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THESIS

THE IMPLICIT FINITE-DIFFERENCE (IFD)
ACOUSTIC MODEL
IN A SHALLOW WATER ENVIRONMENT

by

Mark E. Kosnik

June 1984

Thesis Co-advisors: J.V. Sanders
C.R. Dunlap

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T222197

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Implicit Finite-Difference (IFD) Acoustic Model in a Shallow Water Environment		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis June 1984 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Mark E. Kosnik		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		12. REPORT DATE June 1984 13. NUMBER OF PAGES 128
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Pressure Amplitude, Trapped Normal Mode Propagation, Shallow Water Acoustics, Ocean Modeling

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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in a shallow water environment. The IFD performance in a shallow water environment is analyzed. The IFD results are compared with those of two other models and analyzed in light of basic physical reasoning. In addition, a single sloping ocean bottom is modeled in an experimental tank so that the measured pressure field can also be compared to IFD model results.

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The Implicit Finite-Difference (IFD) Acoustic Model in a Shallow Water Environment

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND OCEANOGRAPHY

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ABSTRACT

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ACKNOWLEDGEMENTS

The author thanks LCDR James Nelson, USN, for his advice and assistance in developing many of the graphics plotting programs. Appreciation is also due LT Patrick LeSesne, USCG, for his many long hours spent assisting in the laboratory while compiling the experimental data. Thanks are also due to Professor Calvin Dunlap for his review of the thesis.

The author also expresses his appreciation to Dr. Alan E. Coppens for his advice and clarification given to the theoretical aspects of the thesis. Finally, the author thanks Dr. James V. Sanders for his time and effort in assisting in all aspects of research and thesis preparation. Without the knowledge, patience, and advice of the Coppens and Sanders team this thesis would not have been possible.

I. INTRODUCTION

A variety of acoustic models exist to predict transmission loss. Each of these models contain inherent strengths and weaknesses. All have shown poor results in a shallow water environment due to difficulties at the ocean bottom where there is an interface between media of different sound speeds and densities.

Since its introduction (Hardin and Tappert, 1973), the parabolic wave equation has been a widely accepted means of solution for accustic propagation. The earliest programs used a split-step Fourier transform algorithm to solve the parabolic equation (PE). Several other solution techniques have been developed primarily to overcome difficulties that occur when the Fourier transform encounters an interface between different media (Lee and Botseas, 1982 and McDaniel and Lee, 1982).

An alternative solution technique that uses an implicit finite-difference (IFD) algorithm was developed by Lee and Papadakis (1979). This method incorporates appropriate interface conditions and allows solutions in shallow water. Starting with the IFD algorithm, Jaeger (1983) developed a computer model to predict transmission loss and accustic pressure based on user specified bottom topography and a single sound speed profile. This computer model uses the mathematical treatment of the horizontal and sloping interfaces developed by McDaniel and Lee (1982) and Lee and McDaniel (1983). It also utilizes several design features and methods incorporated in an earlier computer program developed by Lee and Botsas (1982), and a PE computer model developed by Brock (1978).

The IFD program preserves continuity of pressure and continuity of the normal component of particle velocity at an interface between media having different sound speeds and densities. This feature makes the program unconditionally stable and better able to handle the bottom boundary condition.

Since its development, the IFD program has not been rigorously tested. This thesis analyzes the program's performance in an idealized shallow water environment. The environment includes a simple sloping sand bottom beneath an isospeed water field. The analysis begins by comparing the IFD's predictions with predictions from Jensen and Kuperman's (1980) PE model and Coppens, Humphries and Sander's (1984) image model. The analysis also includes a comparison of the model's estimated transmission loss contours with expectations based on simple physical reasoning. Finally, the thesis describes an attempt to model a shallow sloping bottom in an experimental tank. The tank contains a sand bottom sculptured with a ten degree slope. Laboratory measurements of the pressure field are taken at a frequency of 100 kHz for comparison to the predicted pressure field generated by the IFD. These comparisons of the IFD predictions with other model estimates, theory, and laboratory measurements give an indication of the IFD's performance in a shallow water environment.

II. THE IFD COMPUTER MODEL

A. BACKGROUND

An implicit finite-difference solution technique to the parabolic equation has been studied and refined by many authors. The history of this development is explained in detail by Jaeger (1983), but merits review in order to gain a perspective on an analysis of the IFD computer model. The parabolic equation is an approximation to the elliptical wave equation. The first means of solving the PE used a split-step fast Fourier transform method as developed by Tappert and Hardin (1973). This method requires periodic boundary conditions in depth because of the finite Fourier transform and handles this constraint by introducing an artificial horizontal pressure release bottom below the actual physical bottom. This method of implementing an artificial bottom was incorporated into the earliest PE models developed by Jenson and Krol (1975) and Brock (1978).

Errors in this split-step Fourier transform method were found to be proportional to the horizontal range step and the second derivative of the index of refraction. The second derivative of the index of refraction tends to be large across the ocean bottom interface. Another problem with the split-step method is that it does not consider density differences between two different media at an interface, which influences the reflection coefficient. For these reasons the split-step fourier transform method proved to be poorly suited for a shallow water environment.

The IFD solution method was introduced by Lee and Papadakis (1979) as an alternative to the split-step method. The IFD method employs a second order central difference

formula to solve the PE in the form of a tridiagonal matrix. Although the first version of the IFD did handle discontinuities in the sound speed profile, it did not consider density discontinuities. In 1982 McDaniel and Lee introduced a method to handle a horizontal interface of different densities. In 1983, they extended their treatment to include a sloping interface. It is this version of the IFD that is used in Jaeger's computer program.

E. THE COMPUTER MODEL

The IFD computer program consists of a main program and twenty subroutines. The program utilizes a modular construction so that each of the various subroutines are called from the main program to complete a specific calculation or function when required. The IFD is run interactively from a user generated input file that contains values for frequency, one sound speed profile, a bottom profile, source/receiver depths, attenuation coefficients for both the water and the bottom, and several other input parameters that tell the the program where to obtain a solution within the field. The program initiates the calculations assuming an initial Gaussian pressure field and an artificial pressure release surface at a user specified depth.

Attenuation in both the water and the sediment is handled as complex indices of refraction. An artificial attenuation layer is established beneath the sediment to introduce attenuation above the artificial pressure release surface. The actual magnitude of this enhanced attenuation is calculated using an equation derived by Brock (1978) for use in his PE computer model.

The IFD program steps along the specified bottom profile and makes calculations down through the water/sediment column at each user specified horizonal range. The program

requires that the bottom intersect exactly at a vertical grid point. As a result, for a sloping bottom the program automatically calculates the range step to fulfill this requirement. This computer generated range step is always less than or equal to the user provided range step. As the slope of the bottom increases, the range step must decrease and more calculations and computer time are required to solve the entire pressure field. In some situations an actual modification of the user inputted bottom is required. This occurs with a very gently sloping bottom when the required range step exceeds the user specified range step. Here, the program automatically models the bottom as a series of level and sloping sections in order to ensure the user generated range step is not exceeded. This modification of the bottom is always less than or equal to one-half the vertical grid spacing and the model issues a warning to the user of the modification.

Both printed and graphical output are provided by the IFD. The printed output provides transmission loss and the real and imaginary components of the pressure field at each depth for a specified horizontal range. The graphical output is a plot of transmission loss versus range at the user specified receiver depth.

C. MODEL PROBLEMS/MODIFICATIONS

As this study of the IFD program progressed, it became necessary to modify certain aspects of the model. Most of these modifications were necessary to alter the program output into a more desirable form, but a few were implemented to correct programming deficiencies. Although this section of the thesis discusses the earliest model runs, these results are not presented in detail, but only discussed in general terms because they were obtained before

the computer model was fully modified. All modifications were made only after careful analysis of multiple model runs. It is important to realize that all results generated for comparison to other models and laboratory measurements came from a fully modified version of the IFD.

Since the ultimate objective of this study was to compare IFD model results with laboratory measurements the program was first run with input parameters which exactly modeled conditions in the tank. The experimental set up, explained later in great detail, consisted of a tank that is approximately two meters in length, one meter in depth, with a ten degree sloping sand bottom and a maximum water depth of 35 centimeters(cm). Based on a test case run by Jaeger (1983) of a simple sloping bottom, and by results shown by Jensen and Kuperman (1980) for propagation in a wedge-shaped ocean, it was expected that there would be certain recognizable patterns in the predicted propagation patterns. Specifically, since the speed of sound in the bottom exceeds that in the water (fast bottom), the simple sloping bottom supports trapped normal mode propagation (Coppens and Sanders, 1981). As the acoustic energy travels upslope toward the apex, successively lower modes are cut off and the energy contained in these modes is transmitted into the bottom. The range from the apex at which energy of the lowest mode is transmitted into the bottom is referred to as the dump distance and is a function of wavelength, wedge angle, and the ratio of sound speed in the water to the sound speed in the sediment. An empirical equation that defines this dump distance was derived by Coppens, Sanders, Ioannou, and Kawamura (1978); and was used to identify the expected ranges of these dump distances for the given scenario described above.

The initial unmodified IFD run used the parameters taken from the tank and showed no recognizable patterns in the

acoustic field. There was no observable decrease in transmission loss at the various dump distances as expected. Rather, results indicated widely fluctuating patterns in the acoustic field that appeared inconsistent with both previous studies and simple physical reasoning. Upon closer analysis, it was discovered that although the program was designed to be independent of scale there are several logic statements that are not implemented if the user provided range step is less than one meter. Because the logic statements aren't satisfied, the NEWSEG and NEWMAT subroutines (Jaeger, 1983) are not called correctly. The NEWSEG subroutine initializes the bottom slope and the NEWMAT subroutine computes matrix elements for the program. Obviously, errors in these two program functions seriously distort results. Because of this systematic error in the program it became necessary to scale up all tank parameters. All distances were scaled up by a factor of 1000, and frequency was scaled down by a factor of 1000. Careful analysis reveals that all input parameters are a function of either distance or frequency, so this scaling produces results that model those expected in the tank.

The second modification of the IFD was required to provide a three dimensional graphics display. As discussed earlier, the IFD provides a transmission loss plot versus range at a single depth. However, to study the model predictions in greater detail it was felt that a two dimensional analysis of the model estimates would be more meaningful. As a result a transmission loss contouring program was developed. The program (Appendix B) displays transmission loss contours for range versus depth. Use of the contour plot requires that transmission loss values generated by the IFD be sent to a data disk used by the contour routine. To facilitate this transfer a dummy variable (DIFD) was established in the PRINT2 subroutine to store the transmission loss values and then these values are written to the data disk at the end of the main program.

Another modification of the IFD output was required to change the real and imaginary components of the pressure to a single pressure amplitude magnitude. It was felt that dealing with the pressure magnitude was easier and more meaningful than with the real and imaginary components of the pressure field. This conversion was done in the PRINT2 subroutine and established a new variable (PRMAG) to represent the pressure magnitude.

A final modification in the computer program was made due to a suspected error in the computation of the attenuation in the artificial layer. Physical reasoning dictates that proper implementation of the artificial attentuation would result in a steady drop off in acoustic pressure with depth throughout the artificial layer, with pressure dropping to zero at the pressure release surface. IFD model results on the other hand showed wide fluctuations in pressure with depth in the layer and then only a minimal fall off at the pressure release surface. The equation in the IFD that actually computes the magnitude of the attenuation in the artificial layer was taken directly from Brock's (1978) PE model (Jaeger, 1983). However, Brock's equation was derived with feet as the unit of measurement while Jaeger's model is derived with meters as the unit of measurement. With this in mind, Jaeger's equation should be approximately a factor of three larger than Brock's equation to correct for the difference in units. To correct for this error the equation to calculate attenuation (ATT(I)) in the NEWMAT subroutine was increased by a factor of three. When this correction was implemented, the large fluctuations in pressure with depth were eliminated. The expected drop off in pressure with depth and the fall off of pressure to zero at the pressure release surface were noted.

A listing of the revised IFD computer program with all modifications can be seen in Appendix A.

D. MODEL VERIFICATION

1. Comparison with Jaeger Model Run

In light of the modifications to the IFD computer program just discussed, it was necessary to ensure that the the changes themselves did not introduce errors into the model. So as a first step the modified IFD program was run for one of the test cases used by Jaeger in his original work. This case analyzes propagation in an environment that moves from deep to shallow water. This particular environment is depicted in Figure 2.1 and was chosen because it was very similar to the simple sloping bottom in the tank experiment. A solution is obtained for a bottom with an upslope of 8.5 degrees. An isospeed water field is used with sound speed set at 1500 m/s. Source frequency is 25 Hz. The scenario has a maximum depth of 350 meters and a range of 40 kilometers. Both the source and the receiver are set at 25 meters.

The results using the modified IFD program were the same as Jaeger's for this test case above the artificial attenuation layer. As explained earlier, the program was modified to reflect higher attenuation in the artificial layer, so as to properly reflect the effect of attenuation in this region. The modified program results did not show the large fluctuations in pressure with depth in the artificial layer but rather the gradual decline in pressure towards a value of zero at the pressure release surface. But above the artificial layer the modified program results were identical with those achieved by Jaeger with the original program. Apparently, the minor changes in the program designed to improve on the form of the program output does not hinder the model's ability to achieve a solution in the upper sediment and water column.

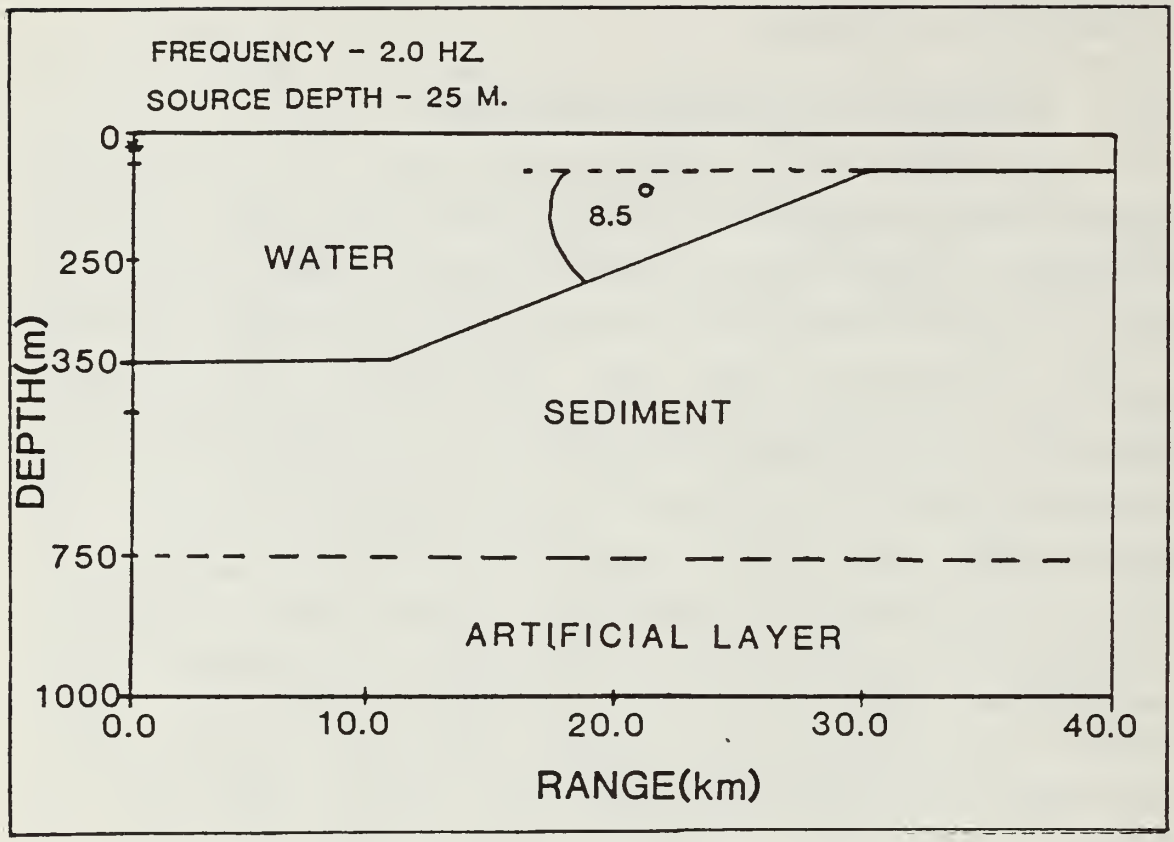


Figure 2.1 Jaeger's Deep-to-Shallow Water Case.

2. Comparison with Jensen and Kuperman Model Run

The second attempt at verifing the IFD model involved a comparison of model results with those achieved with a PE model designed by Jensen and Kuperman (1980). The Jenser and Kuperman Model (JKM) uses a split-step solution technique. Comparison with this particular model was chosen because it is one of the few that obtains a solution in two dimensions. Most acoustic models obtain a solution at only a single depth. In addition, Jensen and Kuperman made their model runs in a simple sloping ocean bottom environment very similar to the scenario of interest modeled in the tank. This environment is depicted in Figure 2.2 and features a gently sloping bottom of 2.2 degrees. The water column has a

unifcrn speed of 1500 m/s. The source is placed just below the midpcint in the channel at 112 meters and is driven at a frequency cf 25 Hz. The maximum depth in this scenario is 200 meters and has a maximum range of 12.5 kilometers.

The Jensen and Kuperman results were expressed as

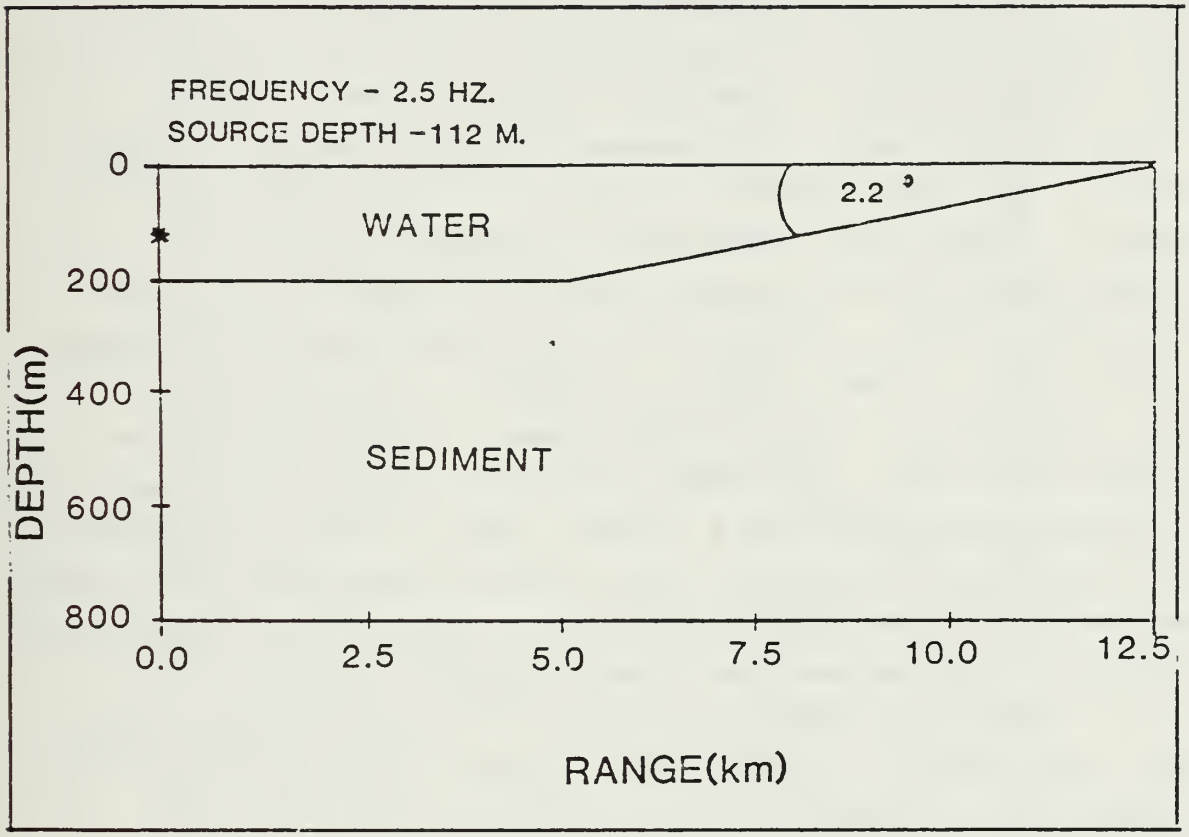


Figure 2.2 Jensen and Kuperman Sloping Bottom Case.

transmission loss ccntours fcr range versus depth. Their study ccncentrated cn transmission loss patterns in the sediment, but results were cbtained both in the sediment and in the water. These results are compared to the IFD results at ranges cf 2.5, 5.C, 7.5, 10.0, and 12.5 kilometers. These ranges were chosen fcr analysis because the JKM results showed the greatest variaticn in transmission loss with

depth and thus, makes for a more meaningful comparison with the IFD results.

The IFD and JKM results can be seen in Figure 2.3 through Figure 2.7. In all the figures, the IFD estimates are shown as a solid curve while the Jensen and Kuperman results are depicted as circular points. The first analysis is at a range of 2.5 kilometers. From Figure 2.2, it can be seen that the depth at this range is 200 meters and is in a flat bottom region. From the results shown in Figure 2.3, it is obvious that both models obtained almost identical results from the surface down to a depth of about 300 meters. There are differences between the two sets of predictions from the ocean bottom to a depth of 100 meters below this point. Below 300 meters the Jensen and Kuperman results show a very slight increase in transmission loss (TL) with depth. The IFD also shows an overall increase in transmission loss with depth but with several fluctuations in transmission loss and a marked peak at about 300 meters. So in general, the results from the two models have the same general tendencies although the IFD appears to show greater detail in results near the water/sediment boundary.

Figure 2.4 shows results at 5.0 km in range. Here, the water depth is still 300 meters and marks the very beginning of the sloping bottom section. For this range the JKM predictions are only available to a depth of 300 meters. The results are nearly identical with those obtained by the IFD. Both models show a relative minimum in transmission loss at a depth of 100 meters and then a gentle increase in TL with depth.

The model results at a range of 7.5 km are seen in Figure 2.5. At this range the bottom depth is about 150 meters and the bottom is sloping. The models show the greatest difference at this range. Both models produce nearly identical results in the water column, but beneath

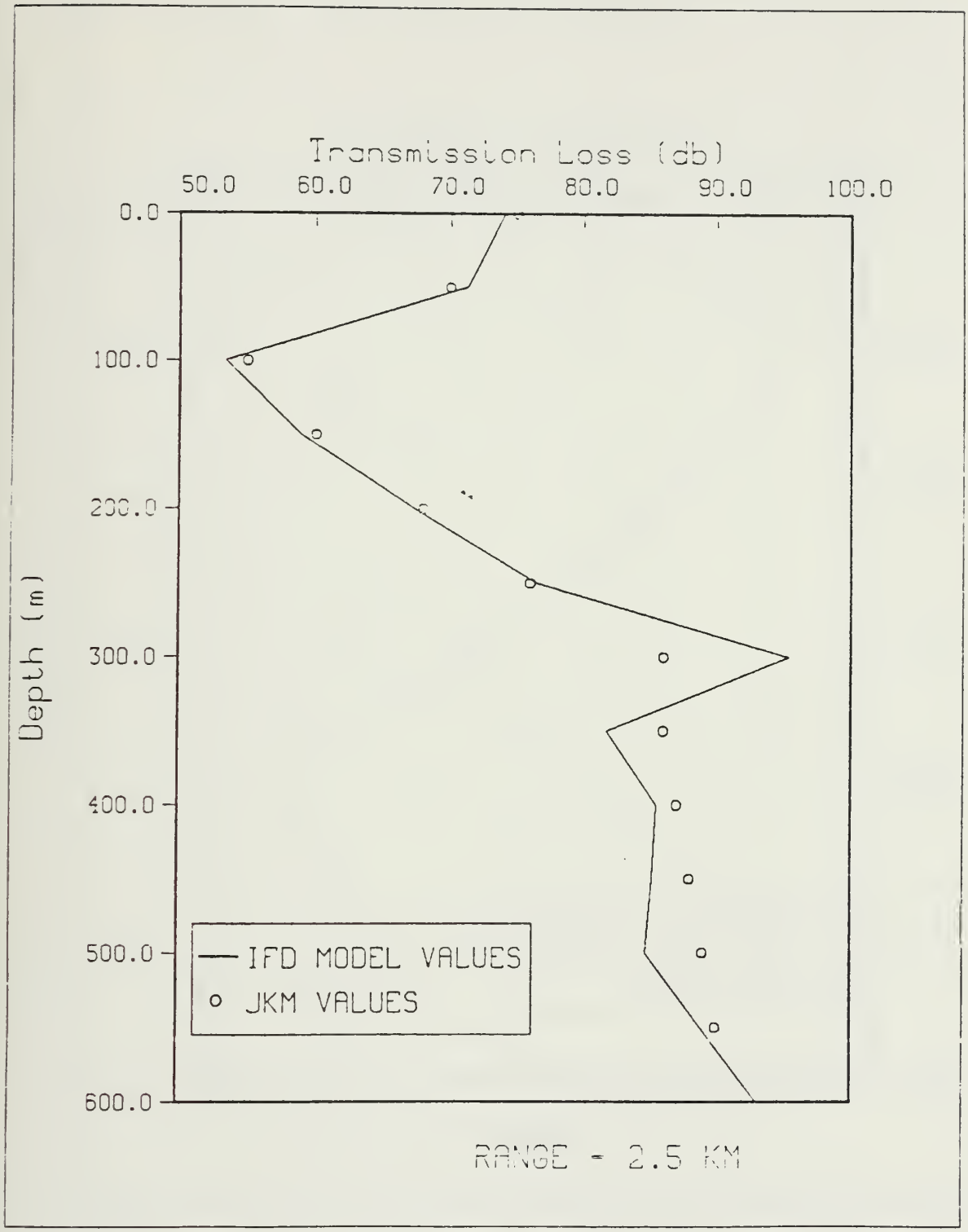


Figure 2.3 IFD and JKM Comparison at a Range of 2.5 Km.

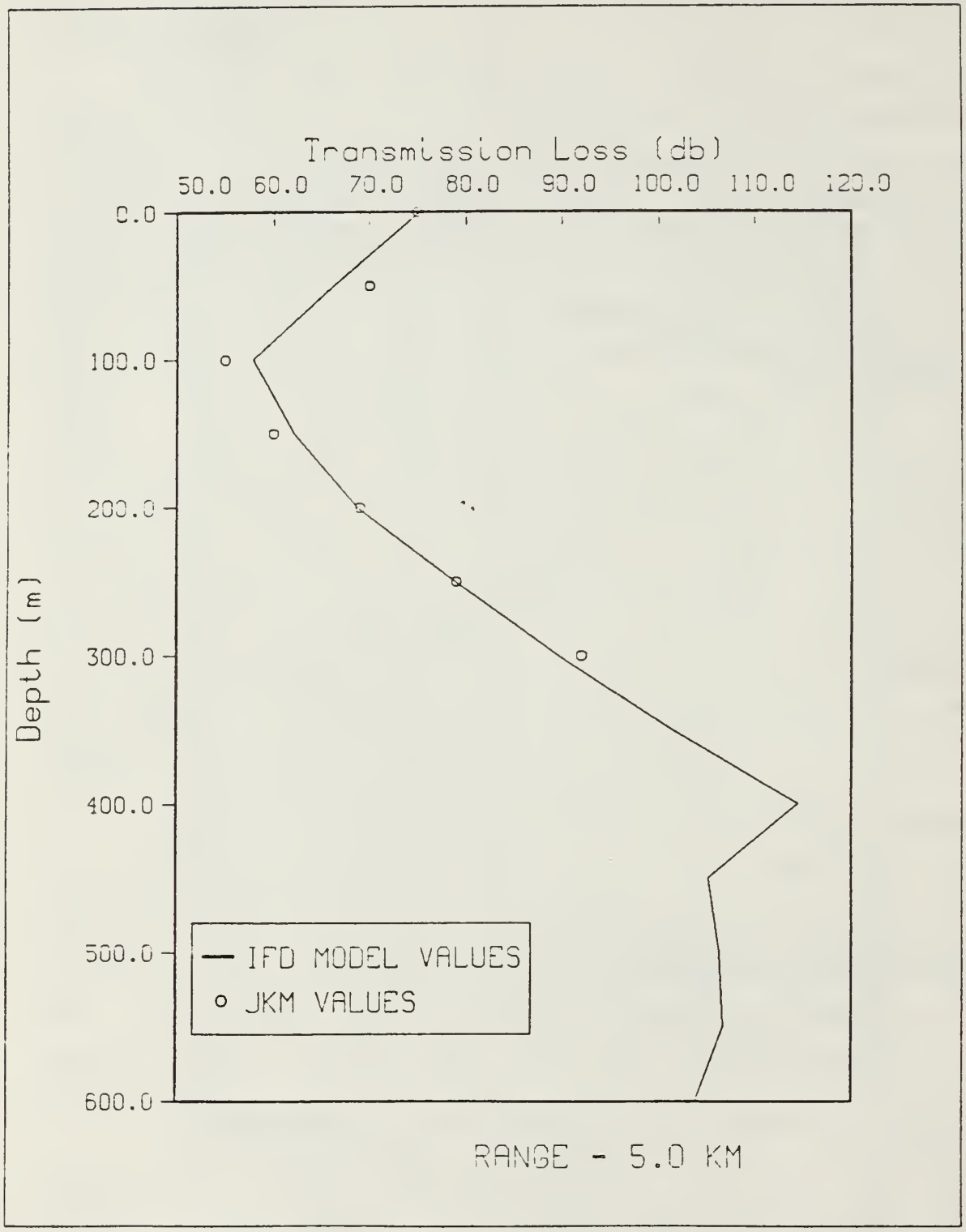


Figure 2.4 IFD and JKM Comparison at a Range of 5.0 Km.

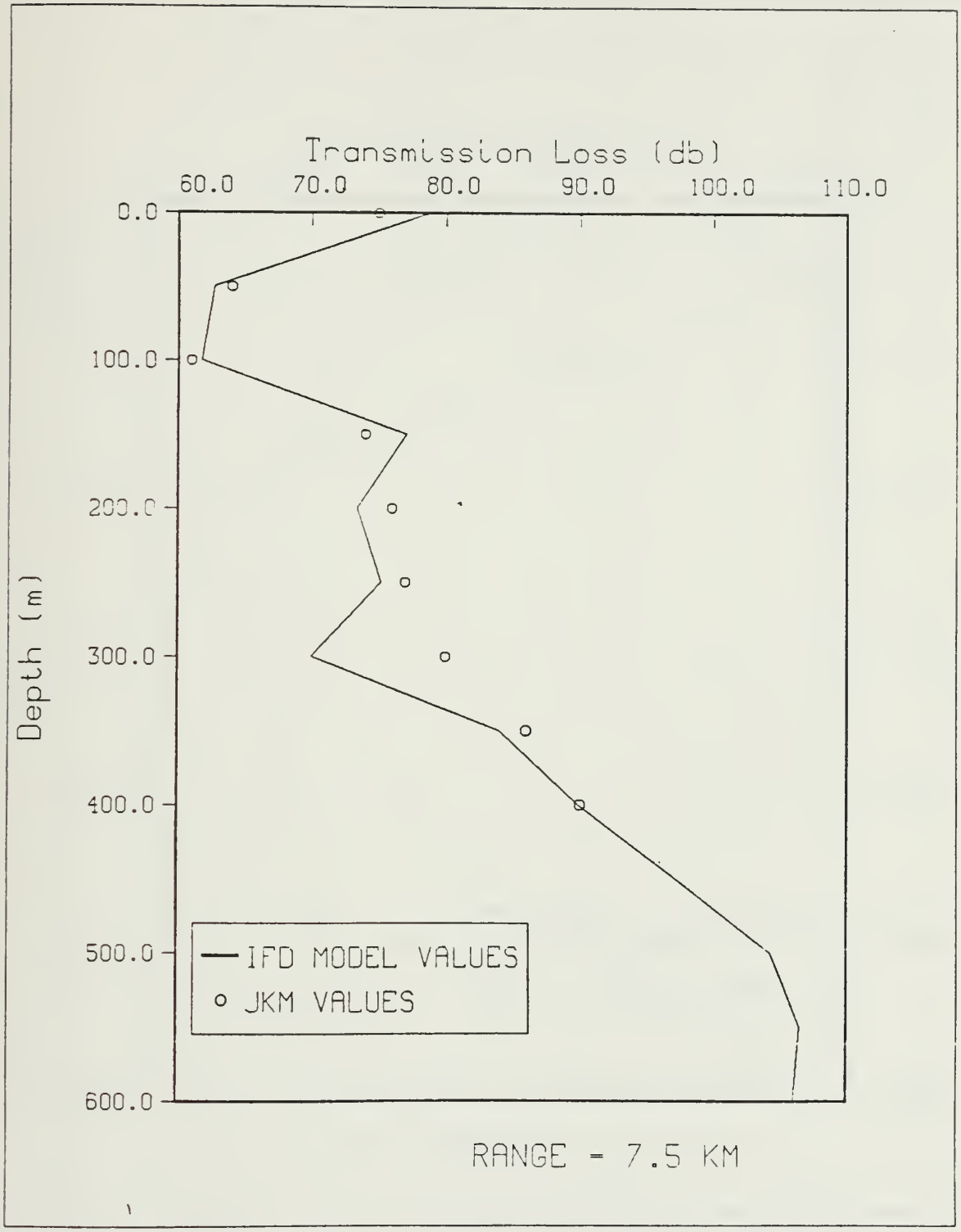


Figure 2.5 IFD and JKM Comparison at a Range of 7.5 Km.

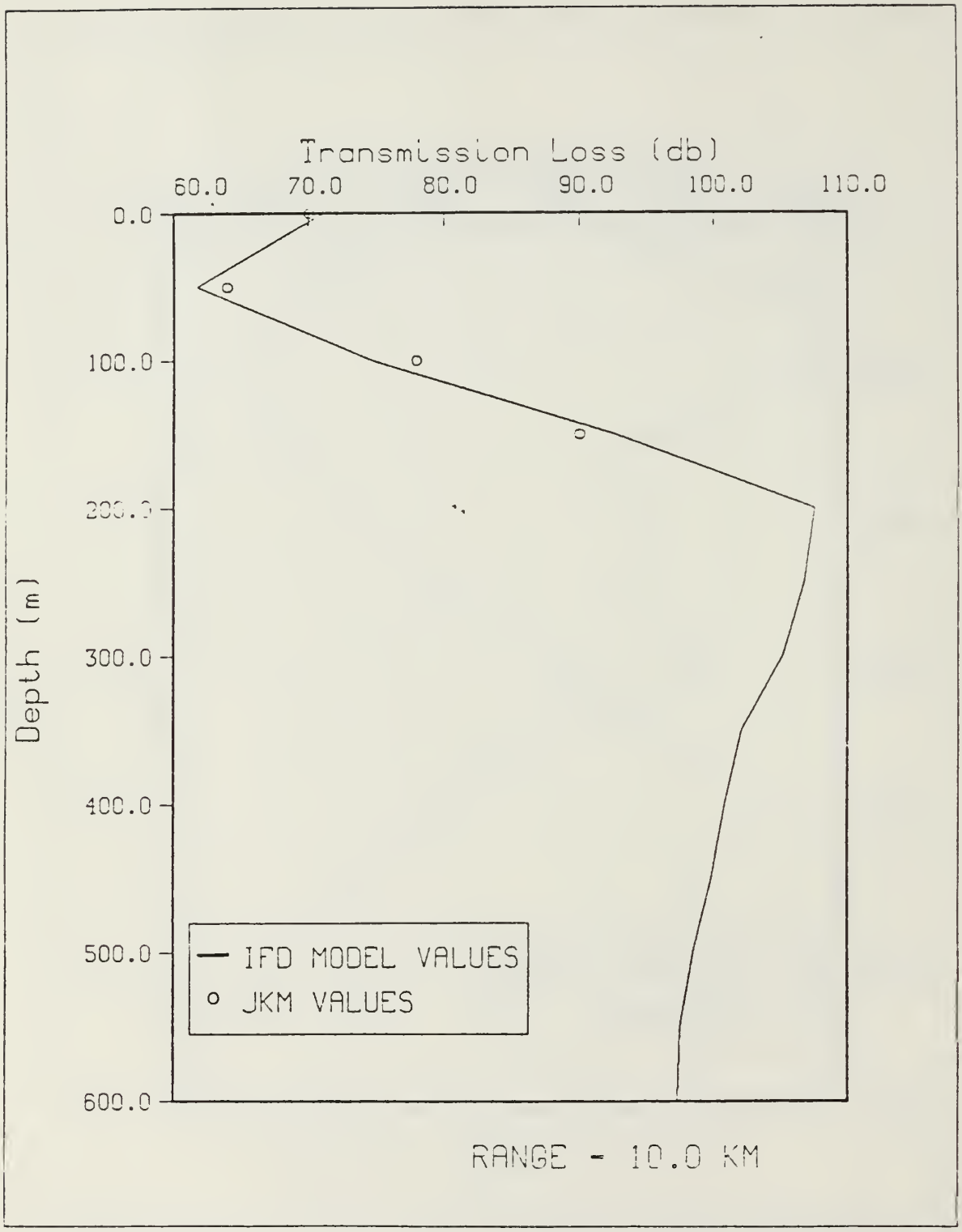


Figure 2.6 IFD and JKM Comparison at a Range of 10.0 Km.

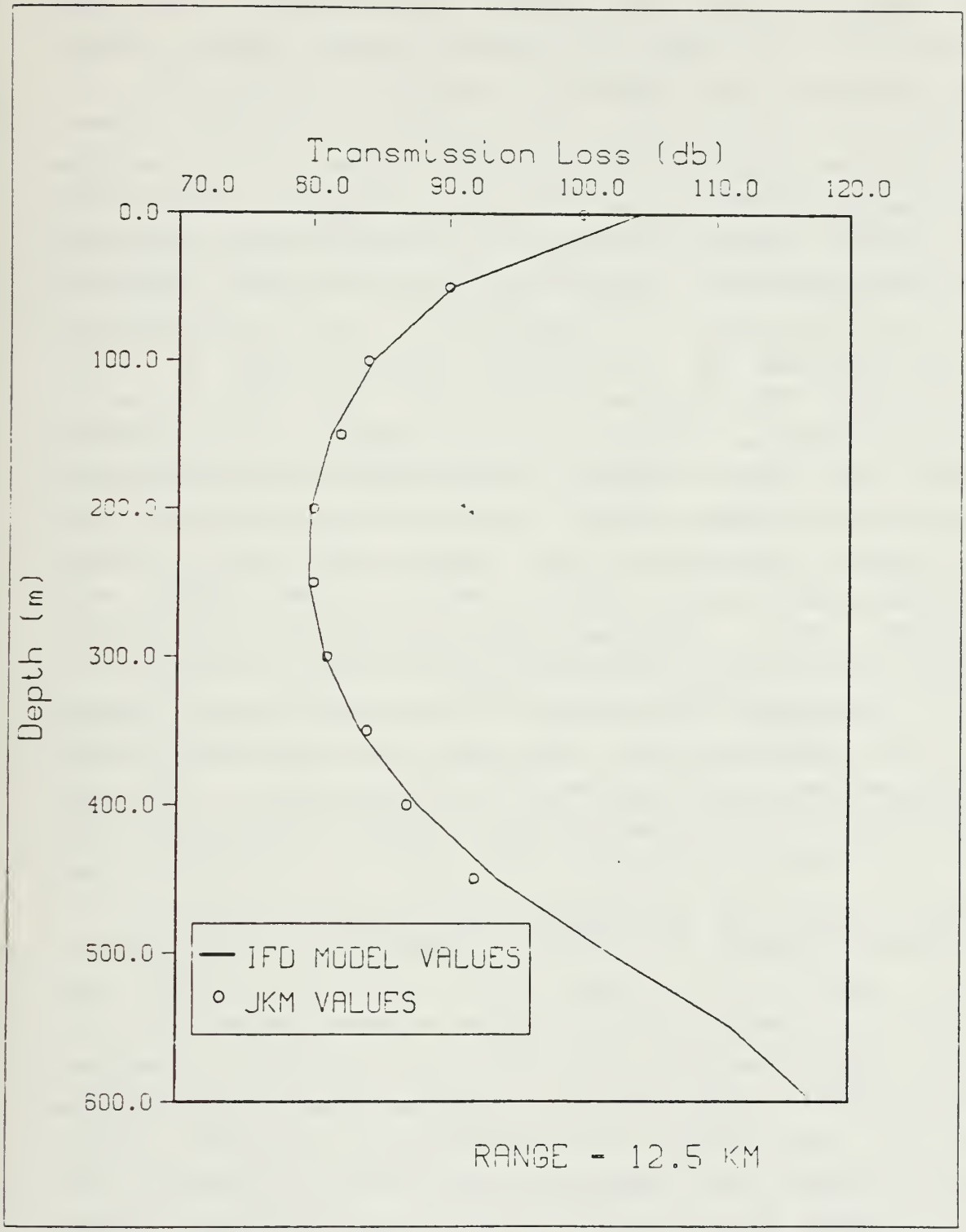


Figure 2.7 IFD and JKM Comparison at a Range of 12.5 Km.

150 meters in depth the model estimates begin to show differences. The Jensen and Kuperman results show a gradual increase in TL with depth below the ocean bottom. The IFD results on the other hand, show a gradual decrease in transmission loss from 150 meters to 300 meters, with a relative minimum at 300 meters and then an increase in TL beneath this depth. Although there are some differences in model estimates near the boundary in the flat bottom sections previously discussed, the differences appear to be greater at the boundary in this sloping bottom case. In these regions away from the boundary in either the water column or in the sediment, however, both models produce similar results. The JKM's difficulty in obtaining an accurate solution at the sediment boundary is not totally unexpected. The model uses a variation of the straight split-step solution technique similar to Brock's computer model (Jensen and Kuperman, 1980), that has characteristically been unsuccessful in obtaining a reliable solution near a boundary.

The results at a range of 10.0 km are seen in Figure 2.6. At this range the water depth is approximately 100 meters and the bottom is again in a sloping region. At this range Jensen and Kuperman results are only available to about 150 meters in depth. For the data available, the models produce nearly identical results. Both models predict a minimum at about 50 meters in depth and then an almost linear increase in TL with depth. The IFD results also reflect a transmission loss maximum at about 200 meters, and then a slight decrease of TL beneath this depth. Data at these depths are not available from the Jensen and Kuperman run. In light of the results obtained at 7.5 km for a sloping bottom case one might expect that the results for the two models would show differences near the ocean bottom. However, since there is only one Jensen and Kuperman prediction available near the bottom for this range, it is

difficult to make any definite conclusions regarding differences in model performance at the boundary.

Results at the apex (range equal to 12.5 km) can be seen in Figure 2.7. Since all estimates are made in the sediment at this range, there is no boundary to contend with. At this range the two models show the best agreement. Both models show a gradual decrease in transmission loss to a depth of about 300 meters and then a gradual increase of TL with depth.

In general, there appears to be good agreement between the IFD and the JKM model results in regions not influenced by a boundary. In both the water and the deep sediment the two models produce similar results. Although this is not conclusive evidence, these similarities suggest that the IFD can successfully model accustic propagation in these regions. Near the water/sediment boundary however, the Jensen and Kuperman and IFD predictions show marked differences. These differences appear to intensify as the bottom becomes more sophisticated. In general, the Jensen and Kuperman results do not seem to show the detail the IFD results do. Considering the different solution techniques employed by the two models, these differences in results are expected.

3. Comparison with Coppens, Humphries and Sanders Model Run

The third attempt at verifying the IFD performance was done by comparing results with an image theory model derived by Coppens, Humphries, and Sanders (1984). This Coppens, Humphries, and Sanders Model (CHSM) uses a saddle point approximation to an image model to solve for the acoustic field. Both programs were run for the scaled scenario modeled in the tank experiment. This scenario is depicted in Figure 2.8 and features a ten degree sloping

bottom. The maximum water depth for the run is 350 meters and the maximum range is two kilometers. The source generates a 100 Hz signal and is set at a depth of 175 meters.

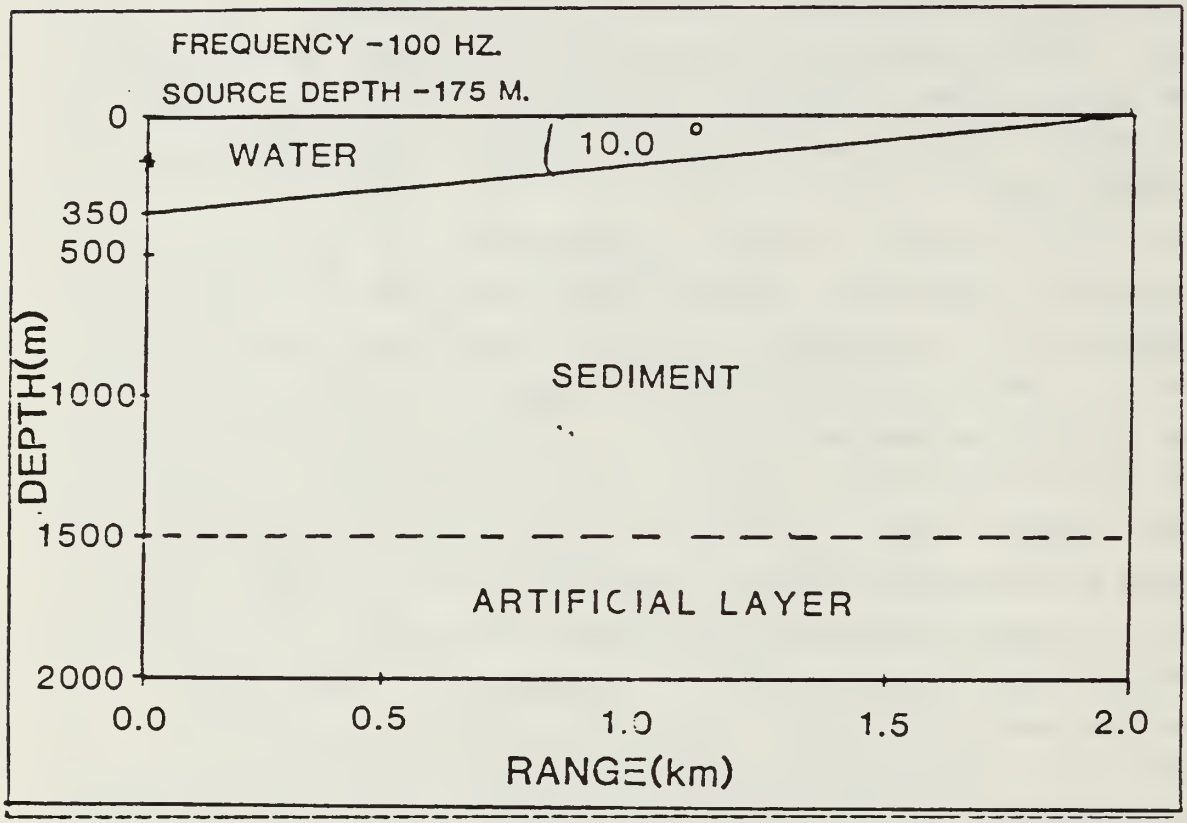


Figure 2.8 10 Degree Simple Sloping Bottom Case.

The image model provides solutions only at the apex. The comparison of predictions at the apex(range equal to 2 kilometers), can be seen in Figure 2.9. In the Figure, the IFD values are plotted as the solid curve while the image model values are shown as circular points. The predictions are shown as values of normalized pressure amplitude for a given depth. The different models produce pressure amplitude values in different units, and thus, had to be normalized to make a comparison of values possible. This normalization was

done for each model by dividing the presssure amplitude by the maximum amplitude predicted by the model.

The results suggest that even though the models predict similar large scale trends in pressure amplitude with depth, there are several differences in detail. The plot shows that both the IFD and the image model predict an almost linear increase in amplitude with depth down to a specific maximum and then a slow decrease in amplitude beneath this maximum. The IFD however, shows the maximum at about 15.5 meters in depth while the image model maximum is deeper at 19 meters. Beneath this maximum the IFD shows a much sharper decrease in amplitude than the image model. The trend in the image model data appears smooth, while the IFD curve reflects several small scale fluctuations.

It appears that both models predict similar large scale trends in pressure amplitude for this scenario. It is difficult, if not impossible, to account for the differences in detail. As a minimum, however, this comparison indicates that the two sets of predictions are consistent with one another and can be considered reasonable in this shallow water environment.

4. Comparison with Physical Reasoning

From model comparisons it appears that the IFD at least makes a reasonable estimation of acoustic fields in a shallow water environment. IFD results are also analyzed in comparison with basic physical reasoning and theory as a fourth attempt at model verification. This analysis examines IFD transmission loss contours for the simple ten degree sloping ocean scenario seen in Figure 2.8. The scenario is two kilometers in range with a maximum depth of 350 meters. The the source generates a signal at 100 Hz and is placed at 175 meters in depth.

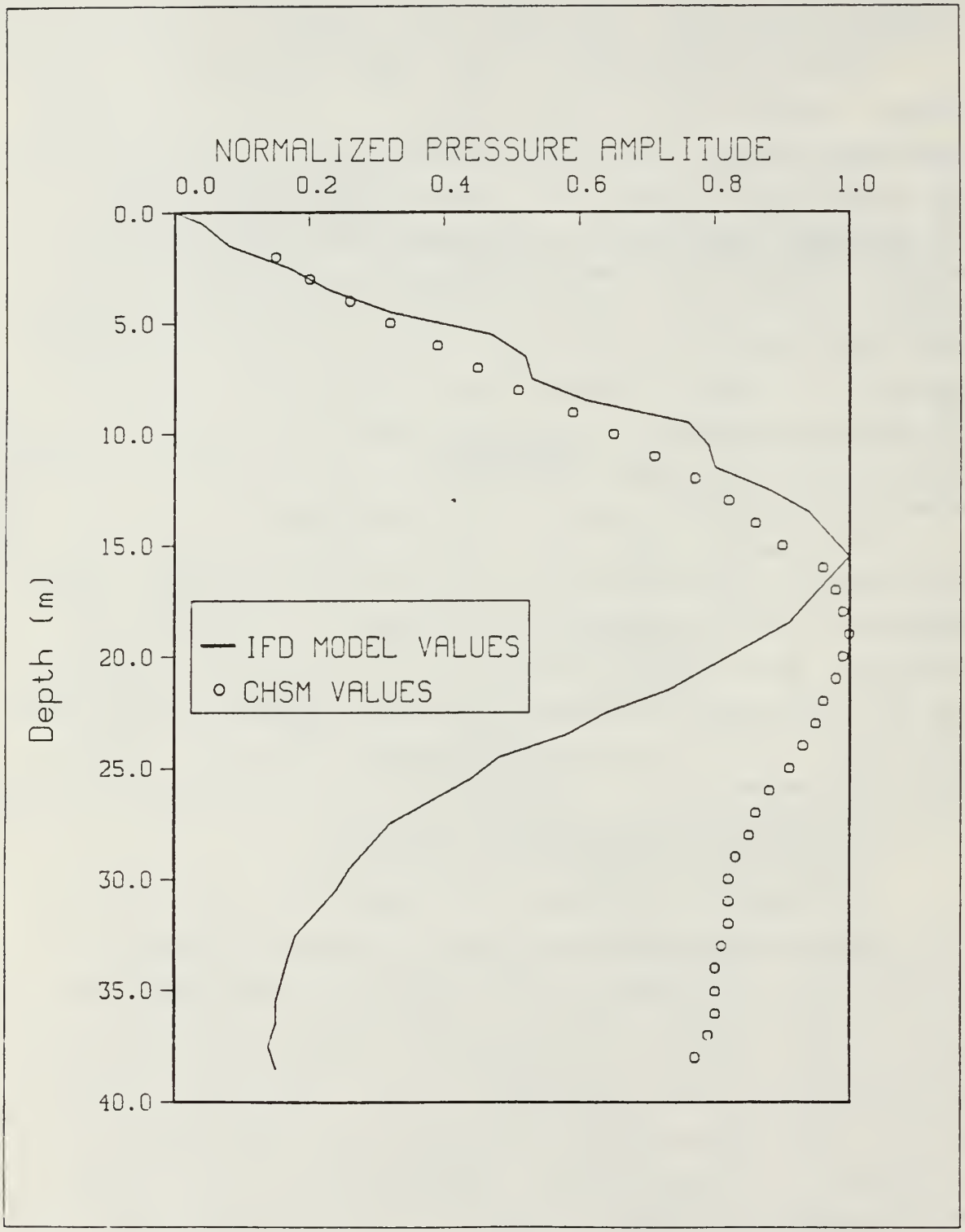


Figure 2.9 IFI and CBSM Comparison at the Apex.

Transmission loss contour plots are displayed in Figure 2.10 through Figure 2.13. All TL contours are expressed in decibels(db) and are shown as a function of depth versus range. In all figures, the ten degree sloping bottom is shown as a solid unlabeled line. The contour plots are displayed over four range subsections due to computer graphics limitations and to emphasize different significant features in the field.

The first figure shows transmission loss contours from the source to a range of 600 meters. The contours in the first 250 meters appear very symmetric, increasing outward from the source in a pattern that resembles spherical spreading. Since the IFD program assumes a Gaussian starting field this early pattern is expected.

From a range of about 300 meters to 600 meters the field in the water appears to be dominated by a surface reflection pattern. From the spotty appearance of the TL contours in this region there is an indication of an interaction of surface reflection and bottom reflection on the contours. It is possible to compare transmission loss maxima with nodes in the surface interference pattern. Based on surface interference theory these nodes should occur where (Kinsler, Frey, Coppers, and Sanders, 1982):

$$SIN(khd/r) = 0$$

or in other words;

$$khd/r = n\pi$$

where:

$n = 0,1,2 \ldots$
r = Range
k = Wavenumber($2\pi/\lambda$)
d = Source Depth
h = Depth of Node
λ = Wavelength.

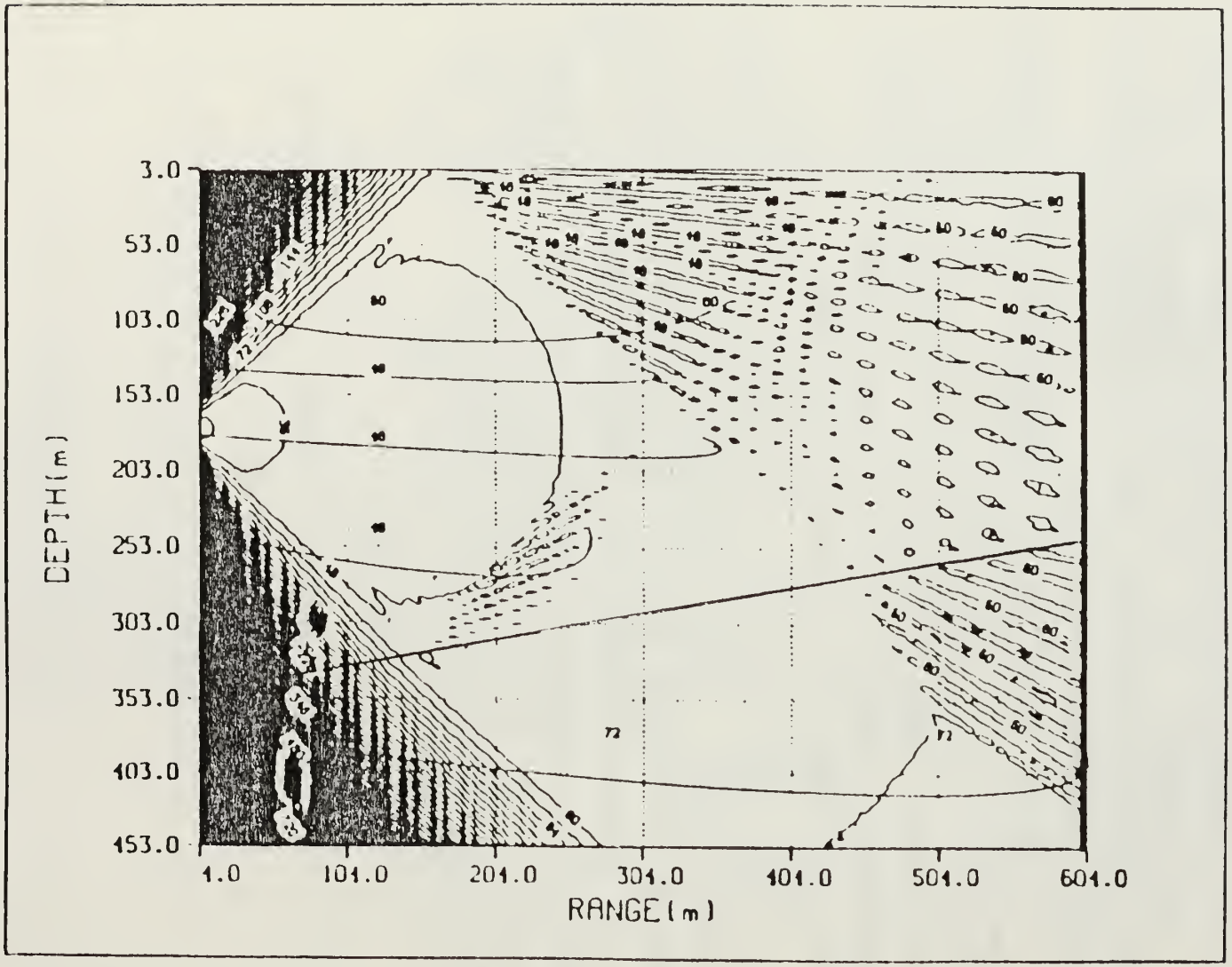


Figure 2.10 IFD TL Contours (dB) from the Source to 604 Meters

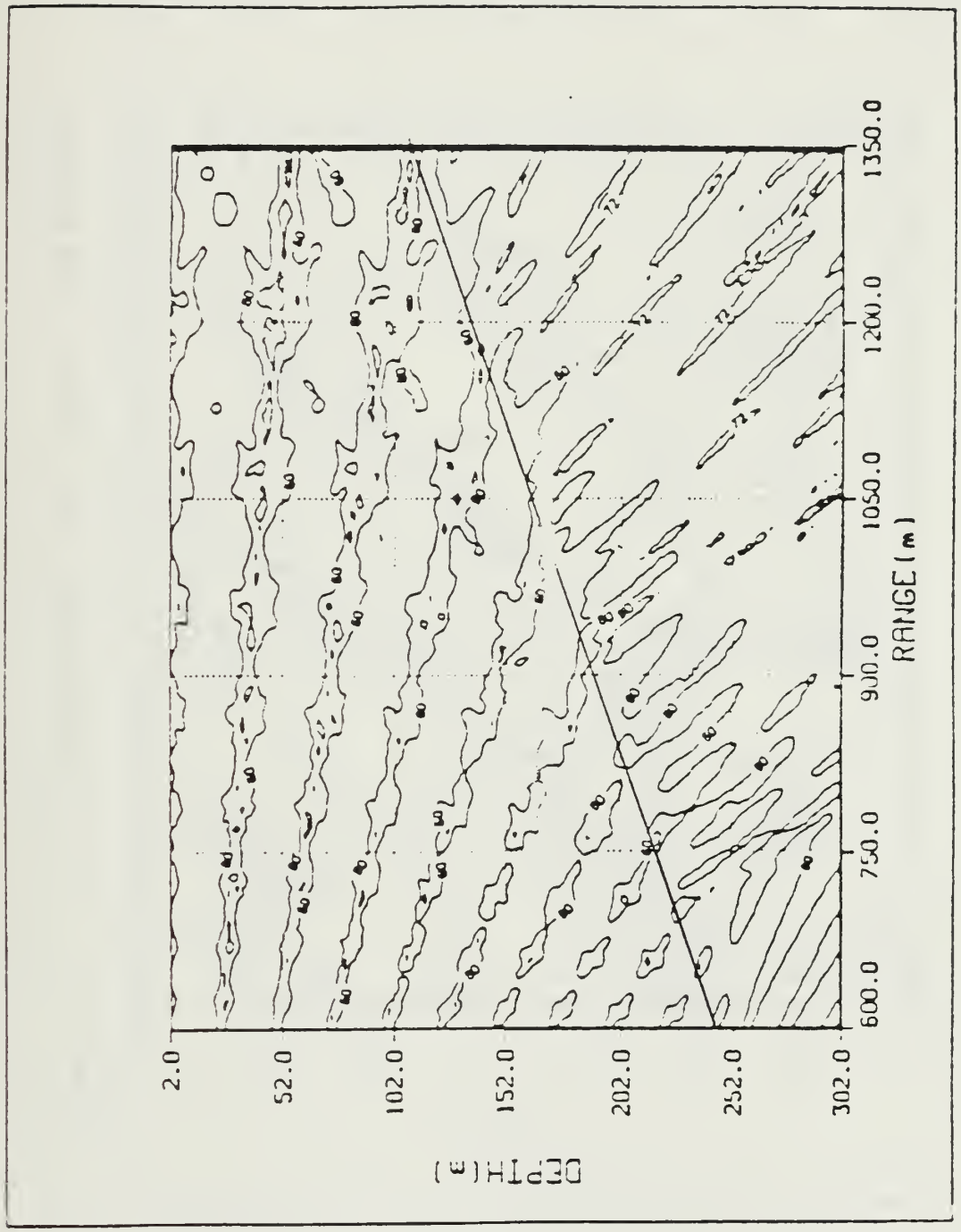


Figure 2.11 IFD TL Contours(db) from 600 to 1350 Meters.

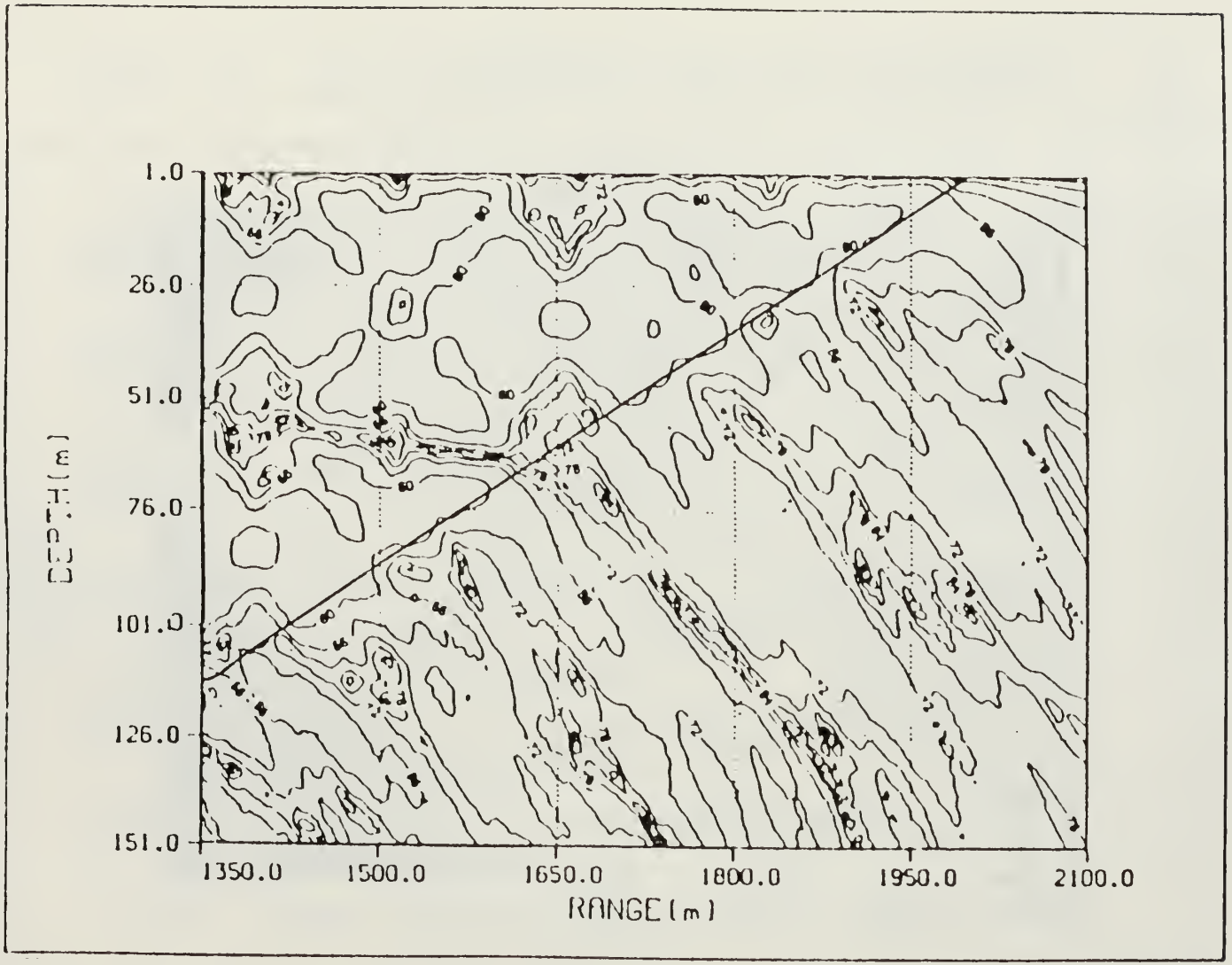


Figure 2.12 IFD TL Contours(db) from 1350 to 2100 Meters.

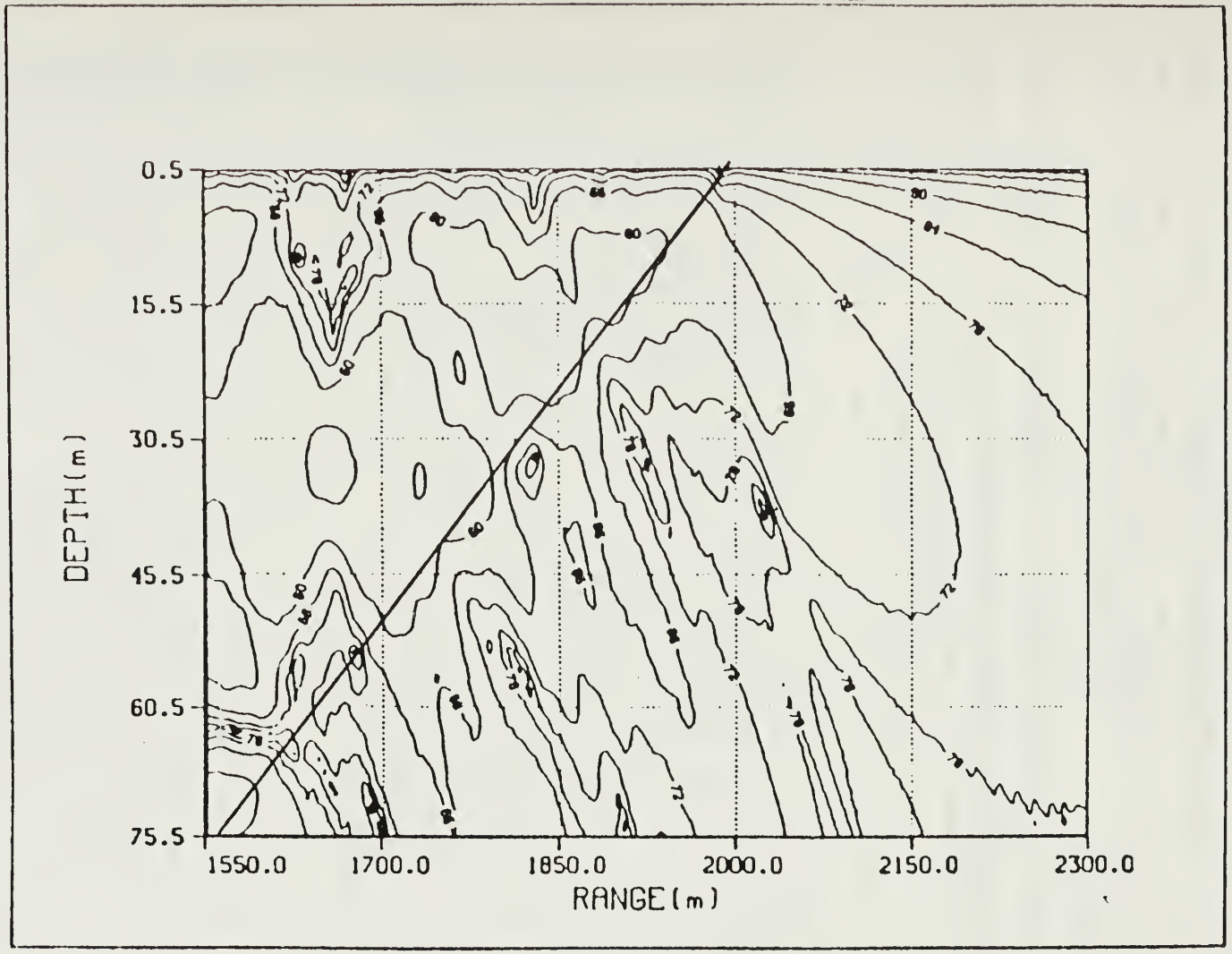


Figure 2.13 IFD TL Contours(db) from 1550 to 2300 Meters.

By manipulating the above equation it is possible to solve for the depth at which the nodes should be observed. For this particular scenario at a range of 604 meters, nodes should occur at integer multiples of 25 meters in depth (25n). Figure 2.10 shows that these transmission loss maxima do exist as expected, every 25 meters in depth at the stated range.

Based on simple physical reasoning one would expect refractive bending along the ocean bottom due to density differences between the water and the sediment. The contour plot reflects a change in basic pattern at the interface. There is a bending of the TL contours that suggest a refractive influence.

Figure 2.11 shows transmission loss contours from a range of 600 meters to 1350 meters. Again in this region the water appears to be dominated by surface reflection. Solving for the nodes in this surface interference pattern at a range of 1350 meters, it is found that these nodes should appear every 55 meters in depth. From the figure it is again seen that TL maximums do occur every 55 meters in depth as anticipated. As in the first figure there is a change in the basic TL pattern at the ocean bottom. The bending appears more accentuated than in the previous figure, but still suggests the influence of refraction at the ocean bottom.

Figure 2.12 displays transmission loss from 1350 meters to past the apex at a range of 2100 meters. In this figure, the dominance of the surface reflection mechanism is less obvious and the TL patterns become more complicated. It is in this region that the influence of trapped normal mode propagation can be seen. As discussed earlier, as accustic energy travels up the slope toward the apex, normal modes are cut off and energy is transmitted into the bottom. According to adiabatic normal mode theory, modal separation

is range dependent (Graves, Nagel, Uberall, and Zaur, 1975 and Coppens and Sanders, 1980). The range from the apex at which the lowest mode is transmitted into the bottom, can be calculated using the following equation (Coppens, Sanders, Ioannou, and Kawamura, 1978):

$$X = \lambda/4 \ SIN\theta_c \ TAN\beta$$

where:

X = Dump Distance Of The Lowest Mode

λ = Wavelength

θ_c = Critical Angle

β = Wedge Angle.

According to adiabatic normal mode theory (Kinsler, Frey, Coppers, and Sanders, 1982), in deep water (near the source) the lower normal modes are far above cutoff and the adiabatic eigenfunctions consist of an integer number of half sine waves with zero pressure at both the top and bottom surfaces. At the cutoff of each mode, the pressure at the bottom must be maximized, resulting in an adiabatic eigenfunction that contains 1/4, 3/4, and 5/4 wavelengths at the respective cutoff distances of 1X, 3X, and 5X for the three lowest modes. From Figure 2.14 it can be seen that as the normal modes travel up the sloping bottom, succesive modes are forced into the bottom at distances where a particular mode reaches a depth at which it can not longer propagate. Also from the figure it is obvious that a source set at mid-depth can not excite the second mode. Since this particular geometry is present in the tank scenario it is expected that the energy associated with this second mode should not be seen. Based on this line of physical reasoning, modes should be dumped into the sediment at the first dump distance, fifth dump distance, ninth dump distance and so on. If these modes are dumped as described

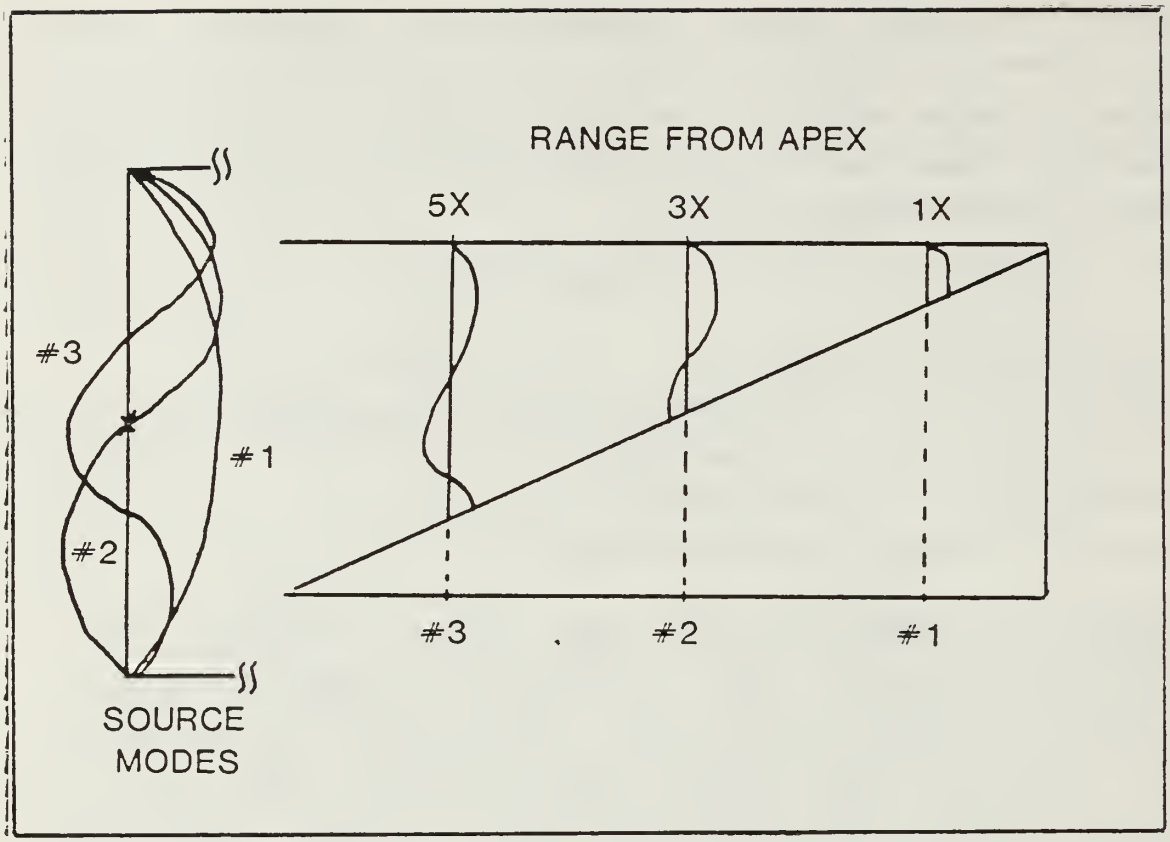


Figure 2.14 Normal Mode Propogation in a Wedge Shaped Ocean.

then they should be seen in the contour plot as reductions of transmission loss in the bottom at ranges of 1952 meters, 1760 meters, 1568 meters, and so on.

From Figure 2.12 it can be seen that there is an obvious decrease in transmission loss at approximately 1950 meters (dump distance #1) and 1760 meters (dump distance #5). There is also a less clearly defined reduction in TL along the bottom at 1565 meters (dump distance #9).

The final contour plot (Figure 2.13) shows transmission loss contours from 1550 meters to 2300 meters. This figure is an extension of Figure 2.12, intended to emphasize how clearly the beam at the first dump distance is defined in the plots. The beam at the fifth dump distance is also

visible but is not nearly as well defined. From this figure, one can also see an indication of a very narrow beam in the sediment at about 1860 meters. This distance corresponds to the third dump distance (second normal mode). Based on adiabatic mode theory the second mode is not expected to be excited. However, adiabatic mode theory is only an approximation of normal mode behavior. This approximation of normal mode behavior becomes less exact as the bottom slope increases and the closer the source is to the apex. The appearance of a narrow beam at the third dump distance indicates that there is a strong possibility that the second mode is present and that the adiabatic approximation is not exact with a ten degree bottom slope.

The basic features of the IFD contour plots are consistent with both physical reasoning and theory. Basic surface reflection and bottom refraction occur where expected and behave as anticipated. In the far field, trapped normal mode propagation is observed and can be verified with simple dump distance calculations. The location of beams dumped into the bottom appear consistent with basic mode theory. In short, the transmission loss contours indicate that the IFD is making reasonable predictions of the acoustic field in a shallow water environment.

5. Verification Summary

It is difficult to say how exact the IFD predictions are for a shallow water environment based on these simple verification techniques. As a minimum it can be said that the model results are at least consistent with other model predictions and expectations based on simple physical reasoning. Model estimates are virtually the same as the Jenser and Kuperman PE model in regions not influenced by a water/sediment boundary. Close to the boundary the IFD results appear to show greater detail and variation than

this FE model. The IFD results also appear consistent with the general trends in pressure amplitude predicted by the Coppens, Humphries, and Sanders image model. Again differences were noted in the small scale structure. Finally, the IFD II contours verify well with basic expectations based on physical reasoning and theory. Surface reflection and bottom refraction patterns are observed as anticipated. Far field normal mode propagation can be verified in the plots using simple dump distance calculations. In short, all verification methods attempted, fail to uncover any inconsistency in IFD performance in a shallow water environment.

III. LABORATORY MEASUREMENTS

A. BACKGROUND

The major attempt at appraising IFD performance involved comparing model results with laboratory measurements. The shallow water environment modeled in the tank is very idealized; a ten degree sloping sand bottom with an isovelocity water column. Although this scenario appears extremely simplistic, it is one that can be reasonably modeled in the laboratory and still approximate conditions in an actual shallow water ocean environment. The methods used to model and measure the acoustic field are relatively untested. Indeed, this attempt at laboratory modeling was performed not only to verify IFD predictions, but also to see if the environment could be successfully modeled in the laboratory.

B. EXPERIMENTAL DESIGN

1. The Tank

A fiberglass coated wooden tank was used. The tank is 304 centimeters in length, 117 centimeters wide and 95 centimeters deep. Sand filling the bottom of the tank was shaped to form the ten degree sloping bottom, and measurements were taken over a range of two meters. Maximum water depth in the tank was 35 centimeters. A 100 kHz source was placed at mid-channel depth (17.5 centimeters). The layout of the tank is depicted in Figure 3.1.

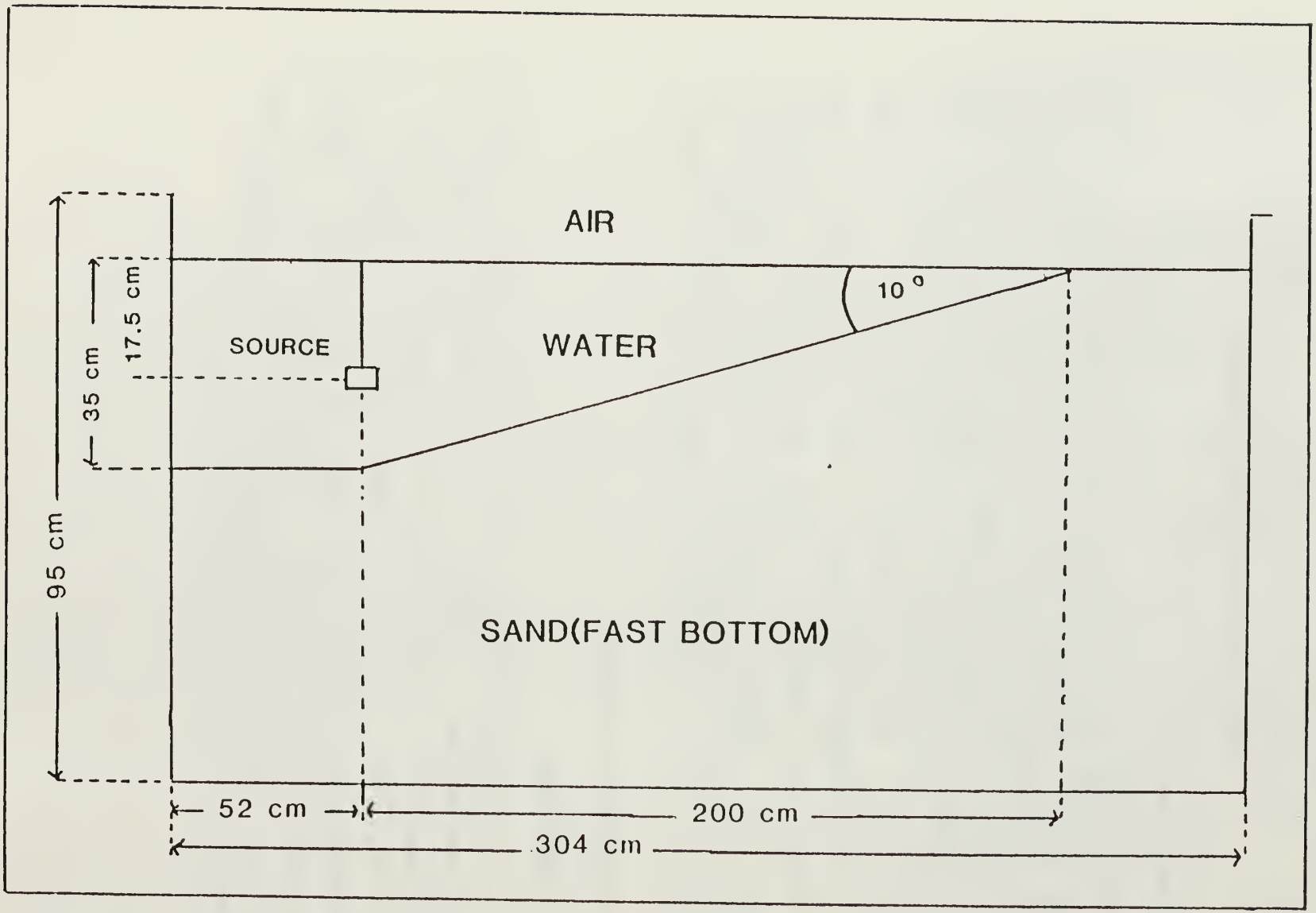


Figure 3.1 Experimental Tank Set Up.

A slope of ten degrees was selected for several reasons. To begin with, even though a ten degree slope is greater than most ocean bottom slopes, it is still small enough to be considered realistic. Perhaps most important, the ten degree slope was selected because given the frequency limitations (discussed later in this chapter) and range limitations, this wedge angle allowed the source to be placed many (41.6) dump distances from the apex. A large number of dump distances was necessary to simulate a distant source.

The bottom material used in the experiment was #30 fine grade sand. The grain size ranged from 0.15 millimeters to 0.70 milimeters. The sand was treated with a technique used by Baek (1984) to remove air from the sediment. This technique used a high speed jet to agitate the sand/water mixture to remove the bubbles and then allowed the sand to settle for several days before the experiment was initiated.

Fresh(tap) water served as the medium in the tank. To remove air bubbles, the water was allowed to settle in a settling tank before being transferred to the experimental tank for use. The water in the tank was periodically treated with chlorine bleach to prevent the growth of biological material.

2. Signal Generating/Receiving Equipment

The acoustic signal used for the measurements was produced by a function generator, sent through an amplifier and then transmitted into the water by a directional transducer resonant at 100 kHz. The dimensions of the active face of the transducer were 7.0 cm in width and 2.0 cm in height. These dimensions resulted in an approximate beamwidth (angle from the acoustic axis to the first theoretical null) of 11.9 degrees in the horizontal and 46.3 degrees in the vertical. The narrow horizontal beam minimized reflections

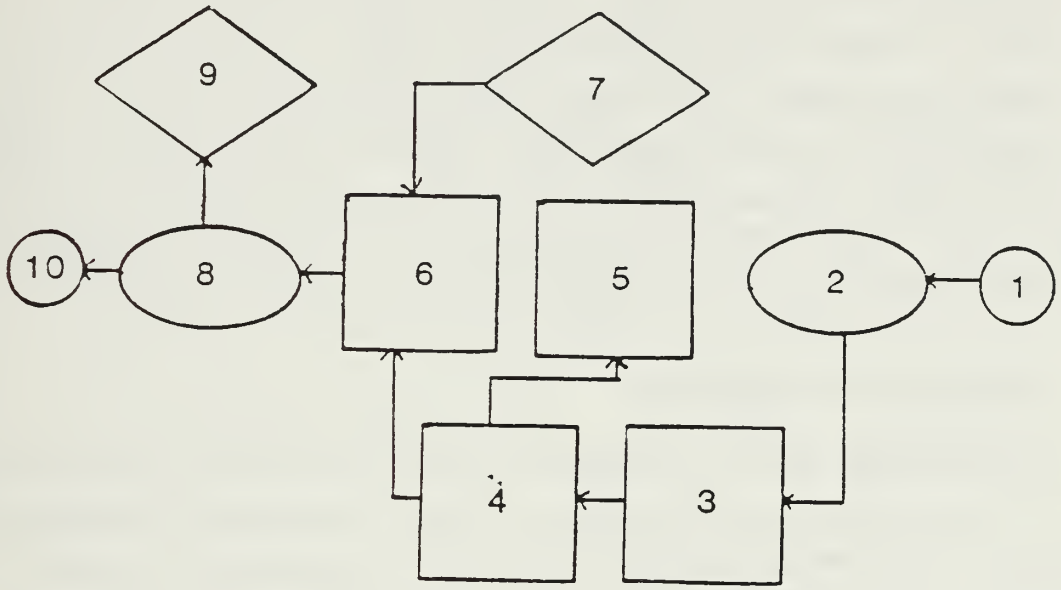
from the sidewalls of the tank, while the wide vertical beam allowed complete ensonification of the channel in the vertical dimension.

The signal was received by an LC-5 omni-directional hydrophone, sent through an amplifier and filter, and then displayed on an oscilloscope and voltmeter. A schematic showing the electronic setup is shown in Figure 3.2.

A frequency of 100 kHz was selected for two practical reasons. First, to avoid particle scattering by the sediment, the acoustic wavelength must be at least three times larger than the grain size of the sediment (Anderson and Liebermann, 1968). The largest grain size in the sand was 0.07 cm, so that a wavelenth of 1.45 cm(100 kHz) was sufficiently large enough to be immune to this effect. Second, the 100 kHz frequency and the properties of the sand provide a dump distance that is small enough to allow the source to be positioned many dump distances from the apex.

Shaping the sand bottom into a ten degree wedge with a uniform and smooth interface proved to be a long and tedious process. To facilitate this modeling, wooden supports (two-by-fours) were mounted along the length of both sides of the tank. These supports were elevated at one end of the tank to achieve the required ten degree slope. A scraping device was constructed with wooden supports and a metal scraping blade that extended across the width of the tank. This scraping device consisted of wooden supports along the top that reached across the tank and could be pulled along the elevated wooden supports on both side of the tank. This scraping device was pulled along the supports repeatedly until a smooth slope of ten degrees was sculptured from the sand.

Holes had to be drilled into the metal scraping blade because when a solid blade was used in the shallow portion of the slope, water trapped behind the blade was



1.) LC-5 HYDROPHONE.
2.) AMPLIFIER (HP 465A).
3.) ELECTRONIC FILTER (SK 302).
4.) OSCILLOSCOPE.
5.) VOLTMETER (HP 400D).
6.) FUNCTION GENERATOR WAVETEK 116.
7.) FREQUENCY OSCILLATOR (GR 1310).
8.) AMPLIFIER (HP 467A).
9.) FREQUENCY COUNTER (HP 5233L).
10.) 100 KHZ TRANSDUCER.

Figure 3.2 Electronic Equipment Schematic.

forced beneath the scraper gouging the smooth bottom. This bottom modeling technique was slow because, once a pass was made over the bottom, the water became turbid and it was then impossible to see the bottom. When the bottom was not visible, it was impossible to see where further smoothing was necessary until the water settled several hours later. In addition, as this smoothing process continued a silty residue became separated from the sand and settled out on top of the sand. This residue would be easily resuspended and eventually had to be removed using a water syphon.

C. MEASUREMENT PROCEDURES

Measurement of the pressure field within the water was done by lowering the receiver in depth at specific ranges of interest. The receiving hydrophone was attached to a pair of micrometers at right angles to one another, that was in turn bolted to a board which spanned the width of the tank. Once the board was placed close to a range of interest, one micrometer was used to give fine adjustments in range and the other in depth.

The measurements were subject to both an accuracy and a precision error. On a given day, with the water level fixed and the cross-tank support set at a particular place in the tank, it was possible to position the receiving hydrophone with an accuracy in depth and range of plus or minus 0.06 centimeters (one turn of the micrometer). To prevent the sand 'inland' of the apex from drying out when not taking measurements, enough water was added to the tank after each data run to keep the sand completely submerged. The next time measurements were taken, water had to to be removed from the tank to reestablish the beach. Because of these small changes in the water level the horizontal position of the beach was subject to a precison error estimated to be within plus or minus one centimeter.

The final decision associated with the measurements centered on whether to use a triggered pulse or a continuous wave (CW) signal. With a triggered pulse it was possible to distinguish the received signal from interference caused by reflections off the side of the tank. On the other hand, by using a triggered pulse there was a possibility that the pulse length was not long enough for the acoustic energy associated with paths reflecting off the top and bottom of the water column to overlap the direct path from the source to receiver. A CW signal would avoid potential pulse length problems, but it would be impossible to distinguish between the actual signal and interference. The use of a source with a narrow horizontal beam reduced the effects of reflections from the side walls, but there was still the possibility of interference from side lobes reflected from the sides.

It was necessary to determine the best means to take measurements. This was done by taking measurements at the same location with different pulse lengths to determine the required pulse length to give consistent results and then comparing these results to those obtained with a CW signal. The third dump distance (14.4 cm from the apex) and just past the tenth dump distance (50.0 cm from the apex) were chosen, and measurements were taken for pulsed signals of 64 and 256 cycles, and a CW signal. These measurements can be seen in Figure 3.3 through Figure 3.5. In the figure depicting results at the third dump distance, the CW measurements are shown as the solid curve, the 64 trigger cycle results are displayed as circular points, and the 256 trigger cycle results are depicted as triangular points. For clarity, the measurements taken just past the tenth dump distance are shown in two figures. Figure 3.4 compares CW results (solid curve) with the 64 trigger cycle signal (circular points). Figure 3.5 compares CW measurements (solid curve) with the 256 cycle results (circular points).

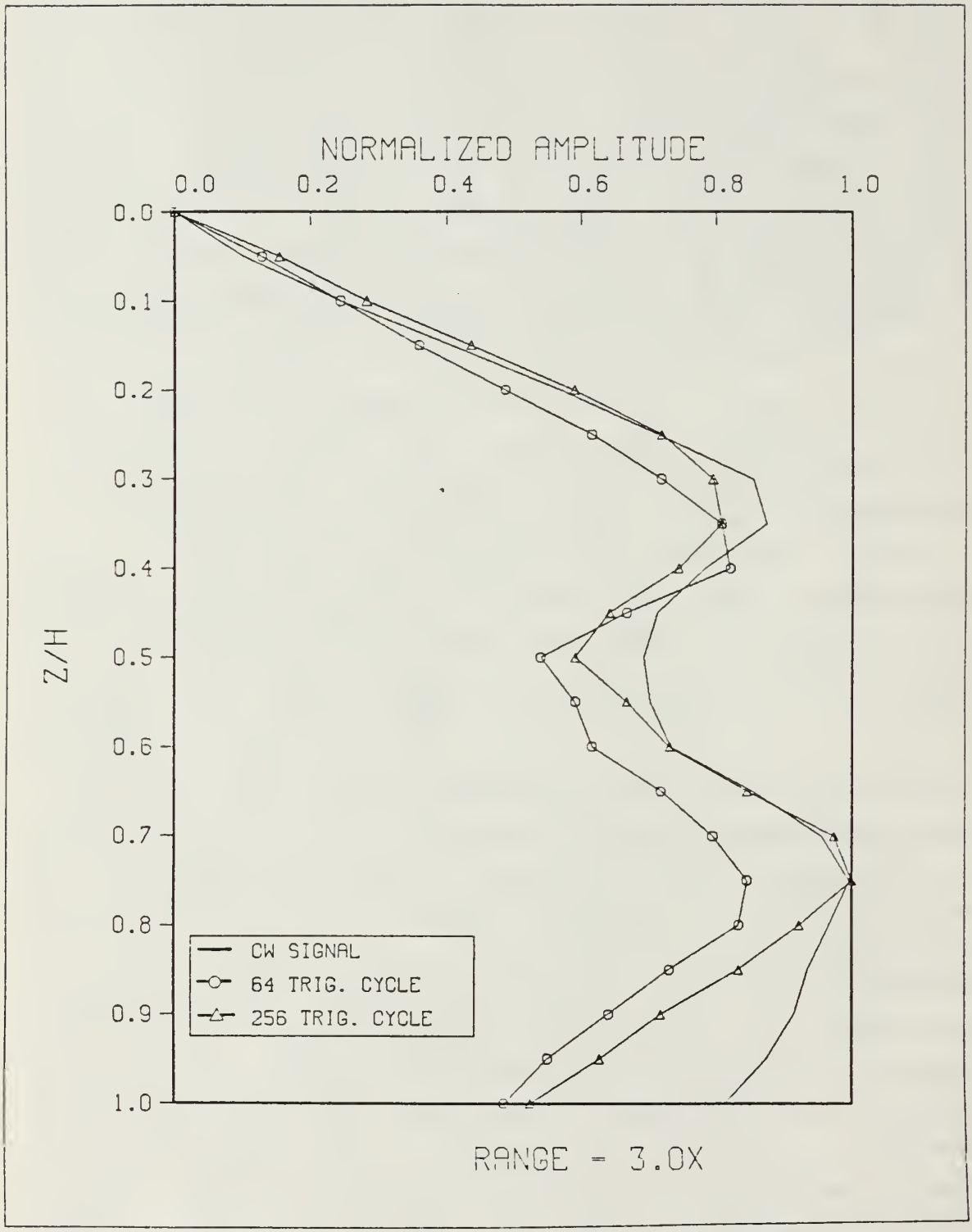


Figure 3.3 Pulse length Analysis at 3.0X.

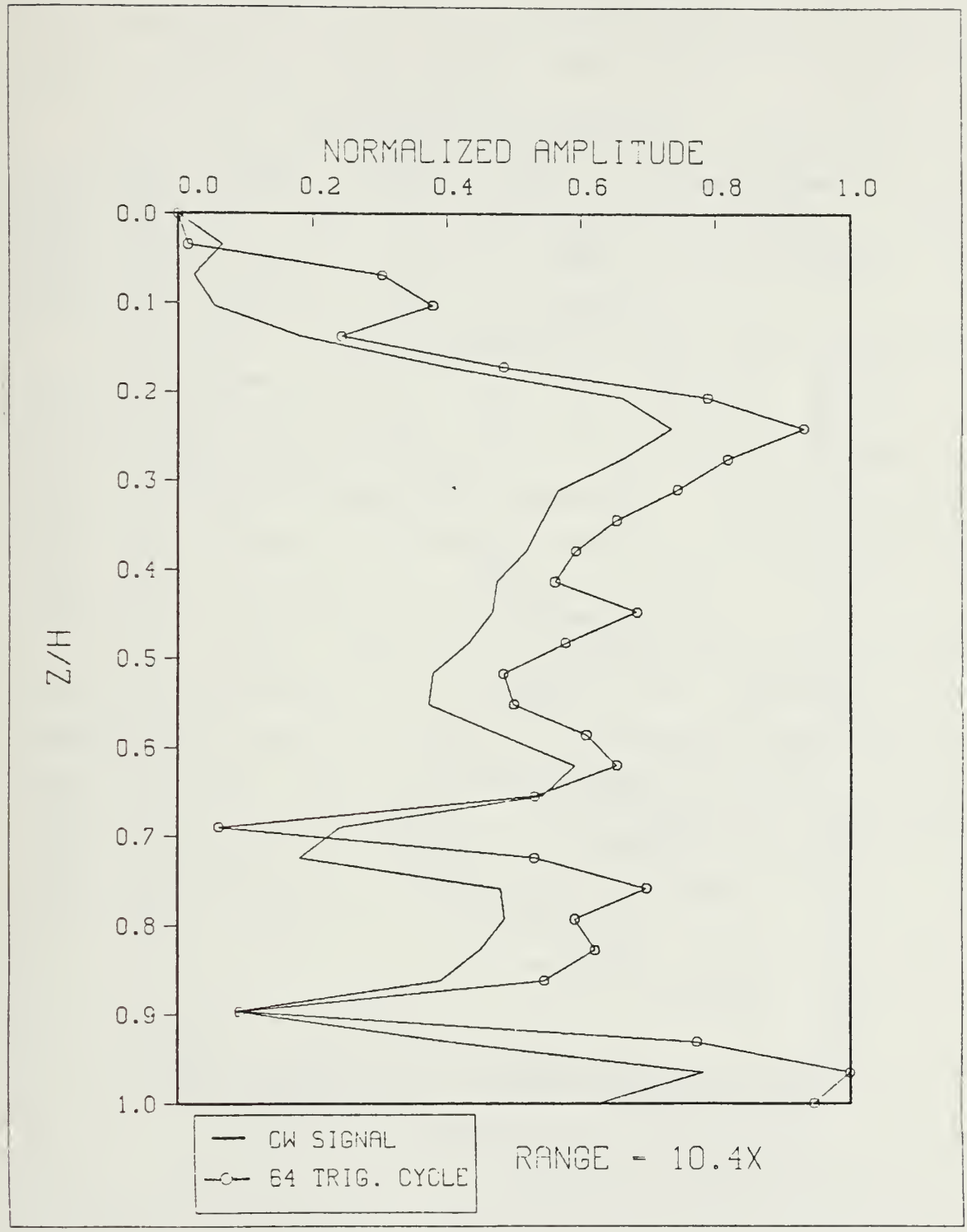


Figure 3.4 Pulse Length Analysis at 10.4X.

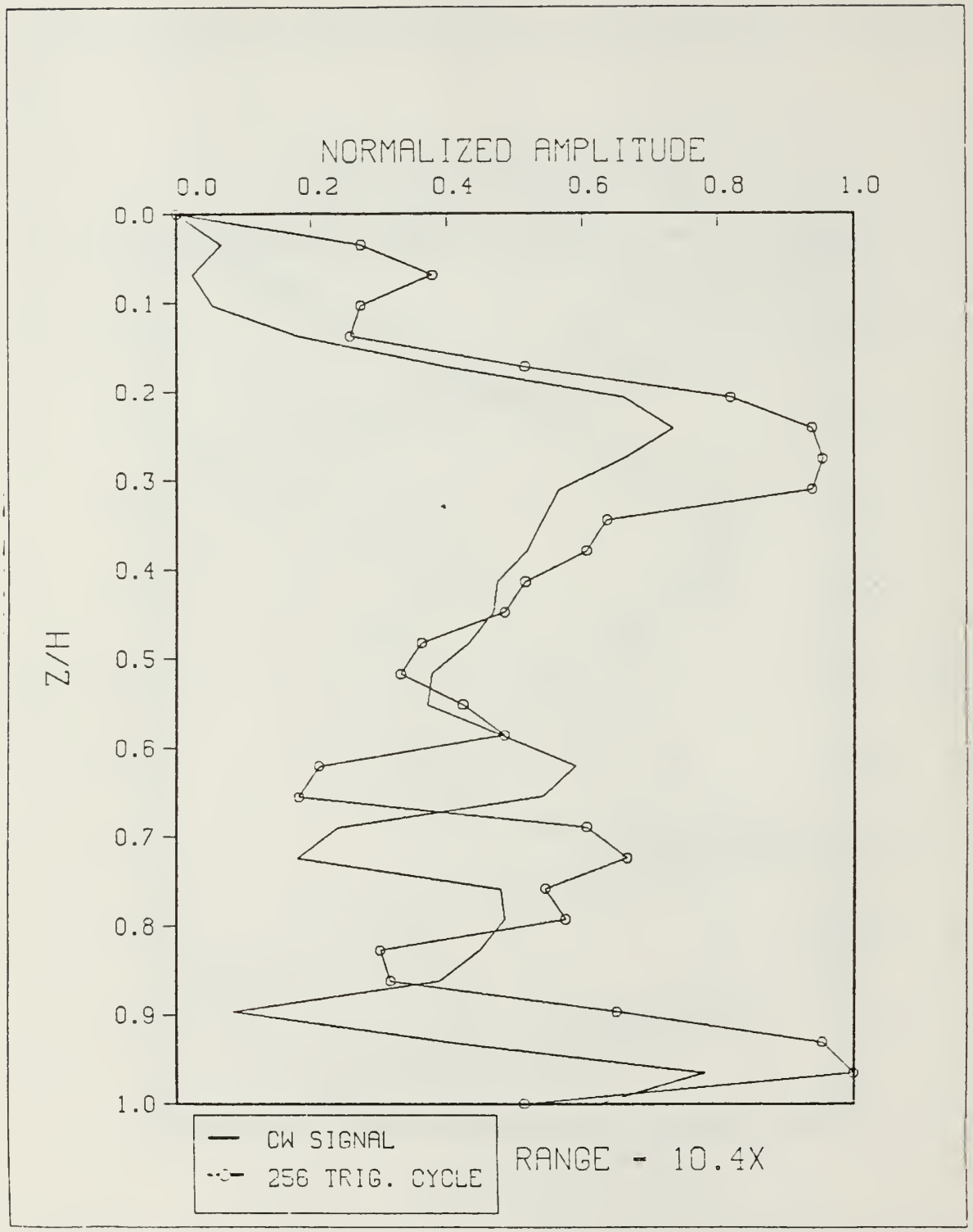


Figure 3.5 Pulse length Analysis at 10.4X.

The pressure amplitude values were normalized by dividing each pressure value by the maximum pressure value in the field. The depth values were also normalized by dividing each depth by the maximum depth.

The results in Figure 3.3 show good agreement between the three curves. In particular, the results for the CW signal and the 256 cycle signal are very similar. The 64 cycle signal shows the same behavior as the CW signal, but differs in magnitude below mid-depth.

The results at 50.0 cm from the apex appear much more complicated than at the third dump distance. Figure 3.4 compares results acheived with the CW signal and the 64 cycle signal. From the figure it can be seen that the two sets of results show good agreement. The measurements depicted in Figure 3.5, which compares the 256 cycle signal and the CW signal show poorer agreement, although the general shapes of both curves remain similar.

These results indicate that interference from the side walls is sufficiently small so that it is possible to make measurements with a CW signal to at least ten dump distances from the apex. Long pulses could also be used, but the difficulty of making voltage measurements with an oscilloscope compared to reading a voltmeter, dictates that measurements should be made with a CW signal.

IV. MODEL RESULT COMPARISONS WITH LABORATORY MEASUREMENTS

A. INTRODUCTION

IFD model predictions and laboratory measurements were obtained for comparison in both a general and detailed analysis. The general analysis compared results every five centimeters from the beach to a range of 50.0 cm from the beach. The measurements were spaced to give results at approximately each of the first ten dump distances. The detailed analysis compared results every centimeter from 3.0 to 11.0 cm from the apex. These measurements were taken to observe the sensitivity of the pressure field to small changes in range.

B. THE GENERAL ANALYSIS

The general anlysis compared IFD results and laboratory measurements at approximately each of the first ten dump distances (every five centimeters from the beach). These measurements were obtained by fixing the receiving hydrophone with respect to the cross board and then moving the board out in increments of five centimeters to measure the desired field as a function of depth at each range. The received CW signal was read on the voltmeter.

The comparisons are shown in Figure 4.1 through Figure 4.10. In the figures, the IFD predictions are displayed as a solid line while the experimental measurements are shown as circles connected by a dashed line. Each pressure value was normalized to unity by dividing it by the maximum pressure value for the respective curve. The depth values were also normalized by dividing each depth by the maximum depth in the water column.

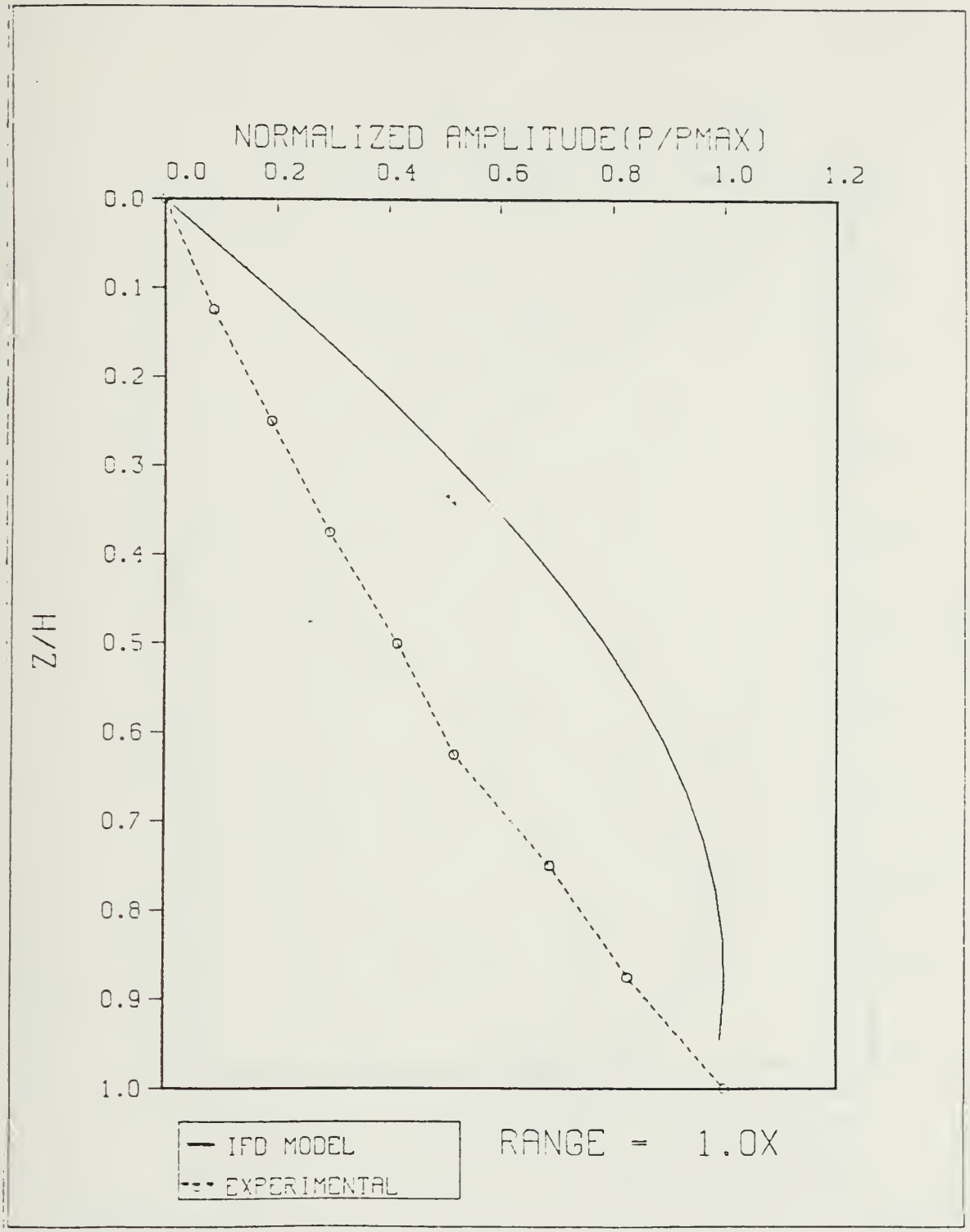


Figure 4.1 Comparison of Results at 1.0X.

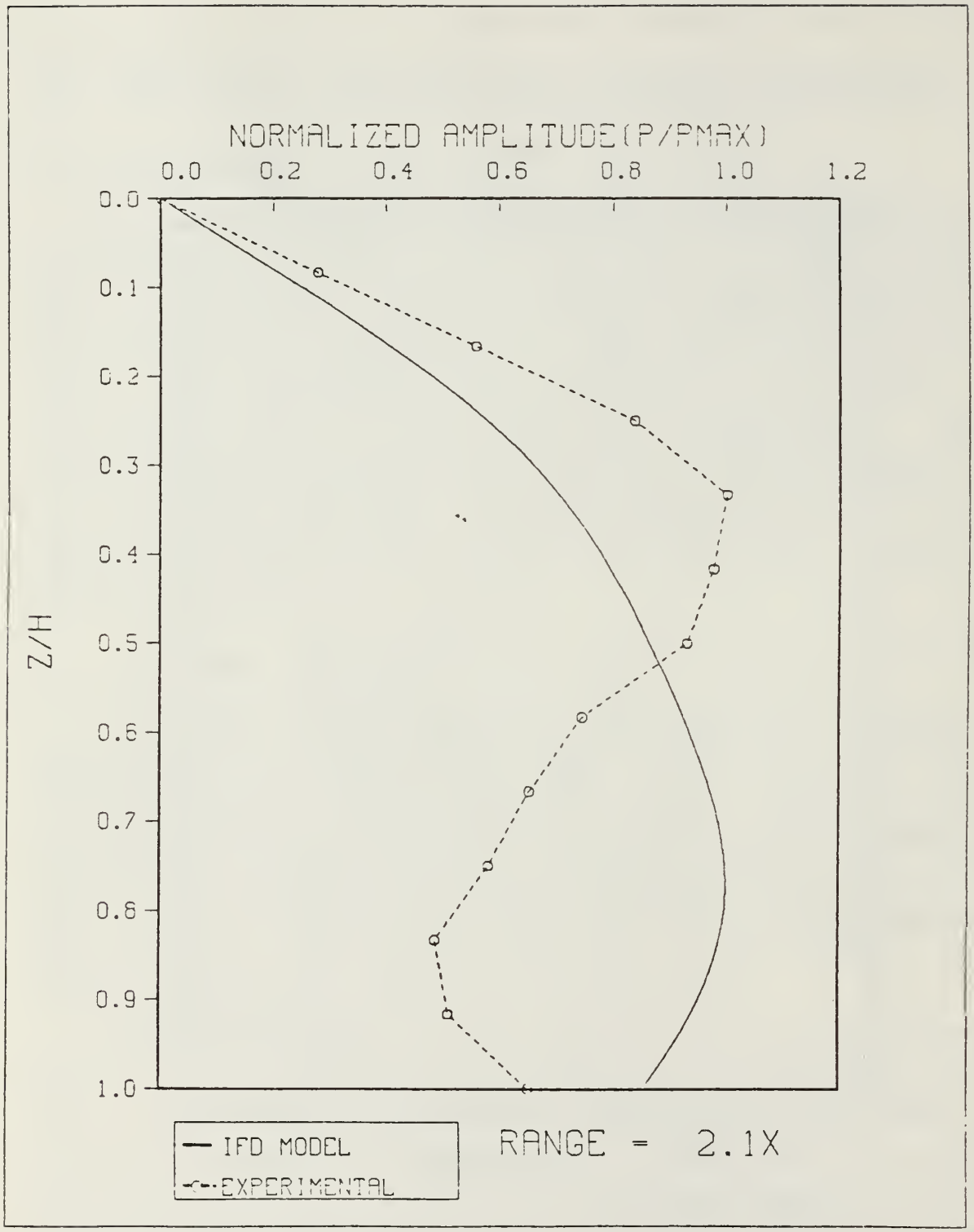


Figure 4.2 Comparison of Results at 2.1X.

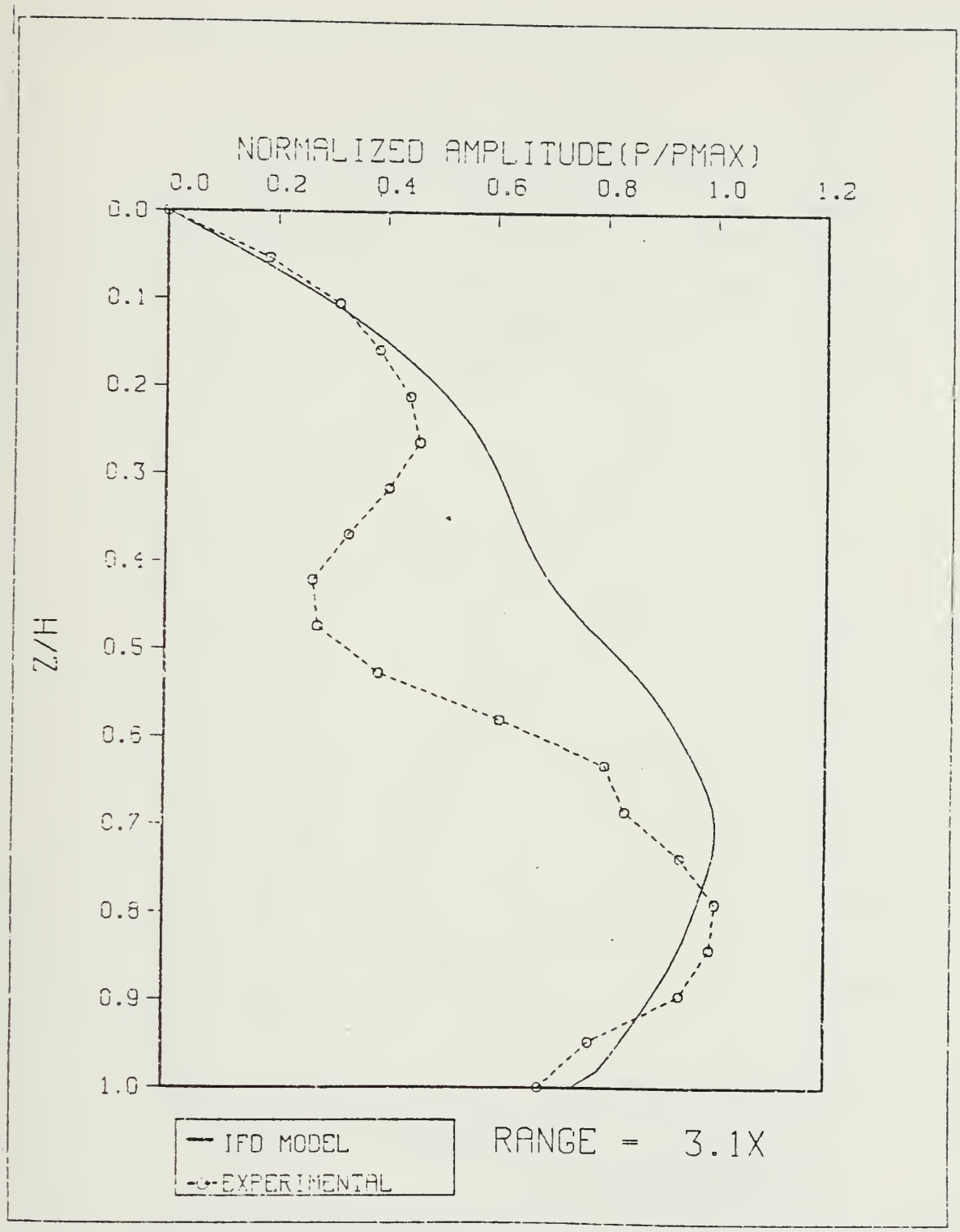


Figure 4.3 Comparison of Results at 3.1X.

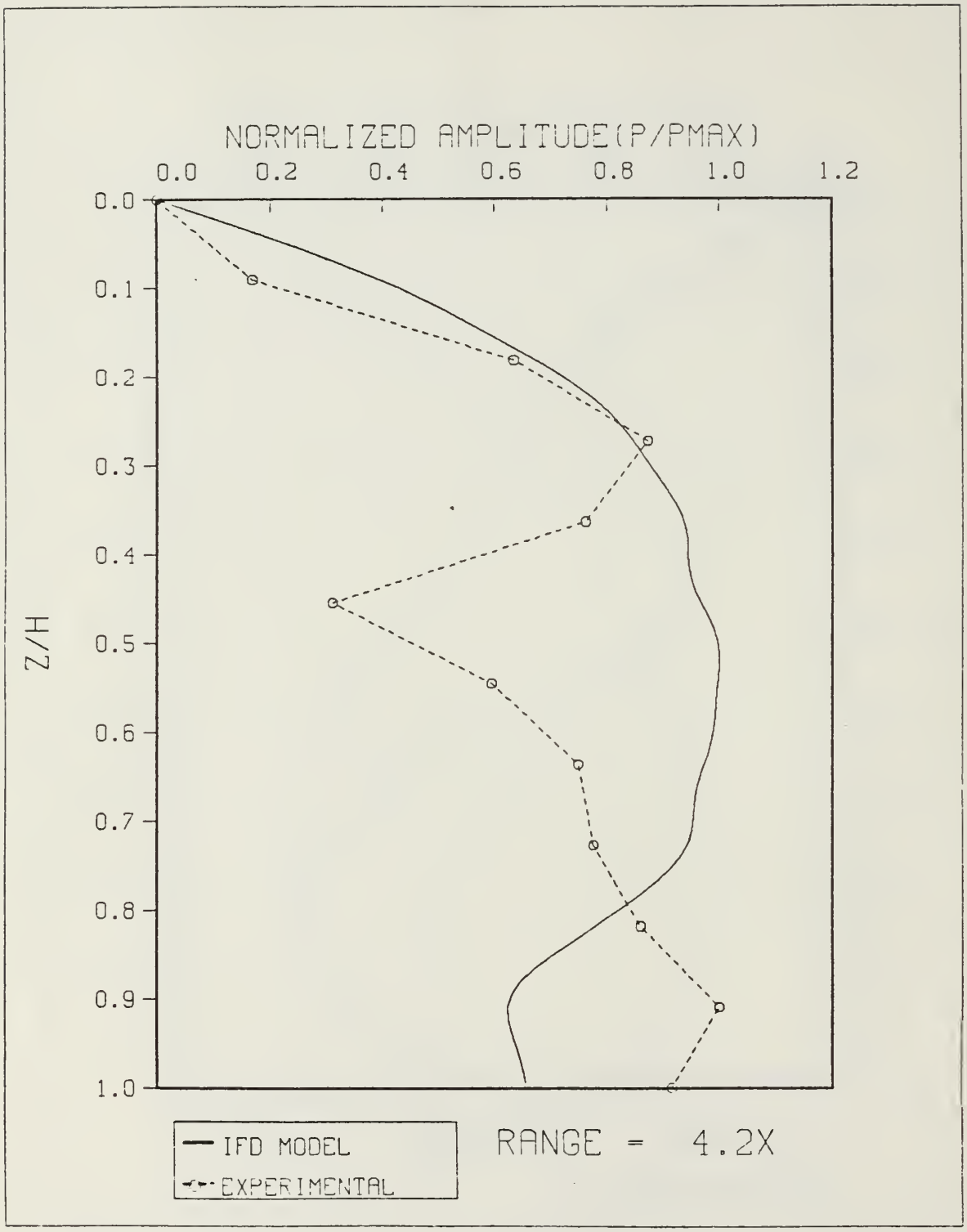


Figure 4.4 Comparison of Results at 4.2X.

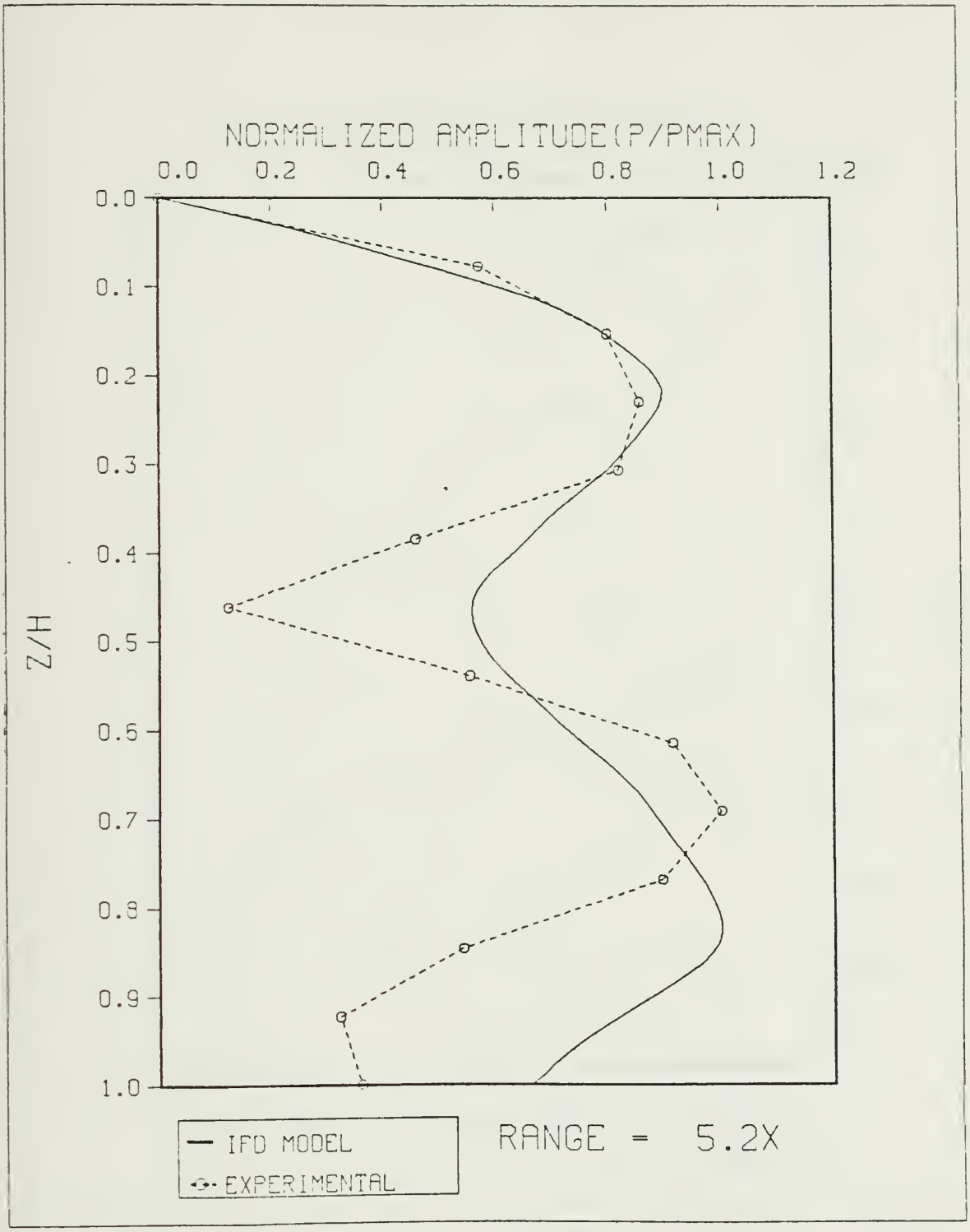


Figure 4.5 Comparison of Results at 5.2X.

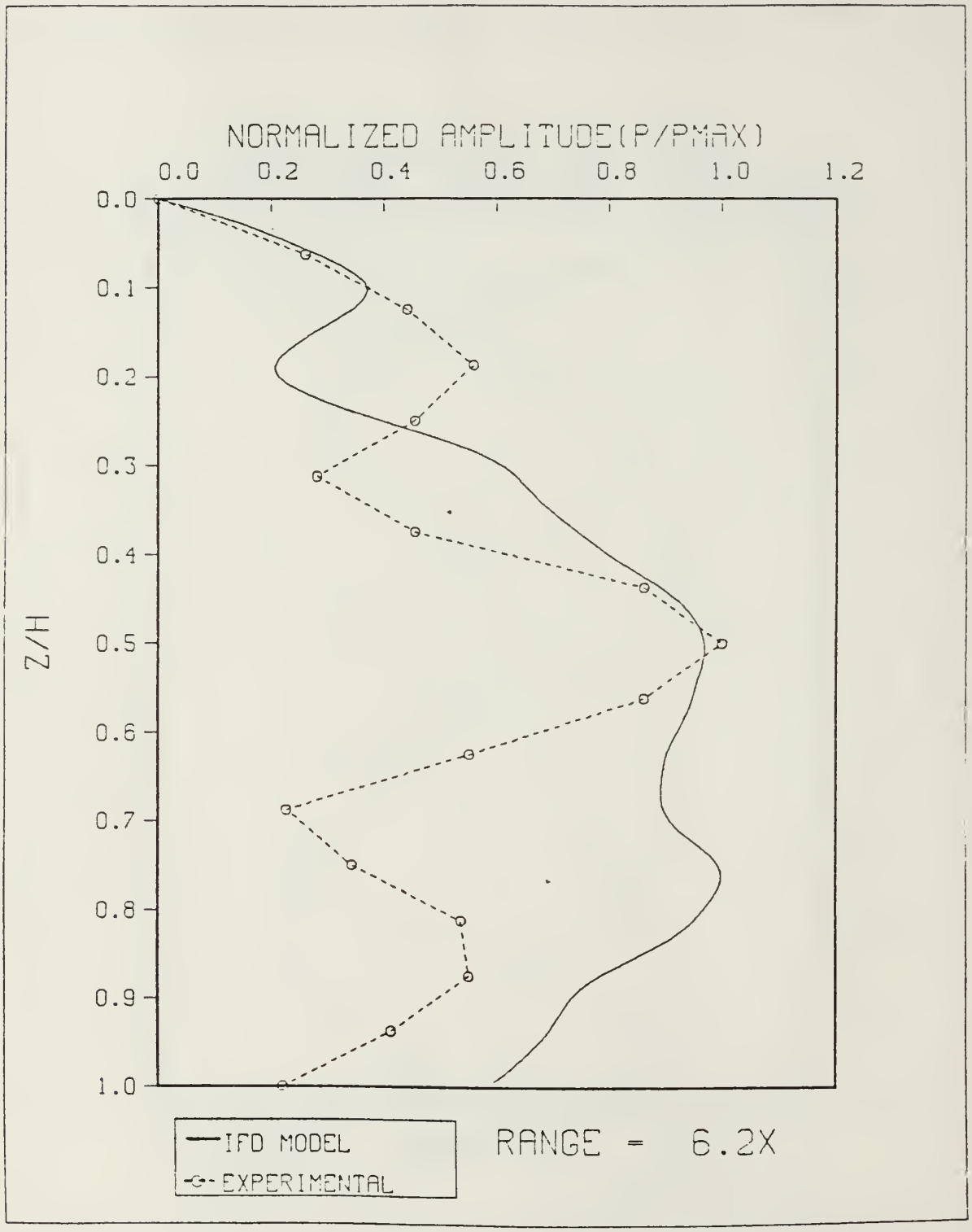


Figure 4.6 Comparison of Results at 6.2X.

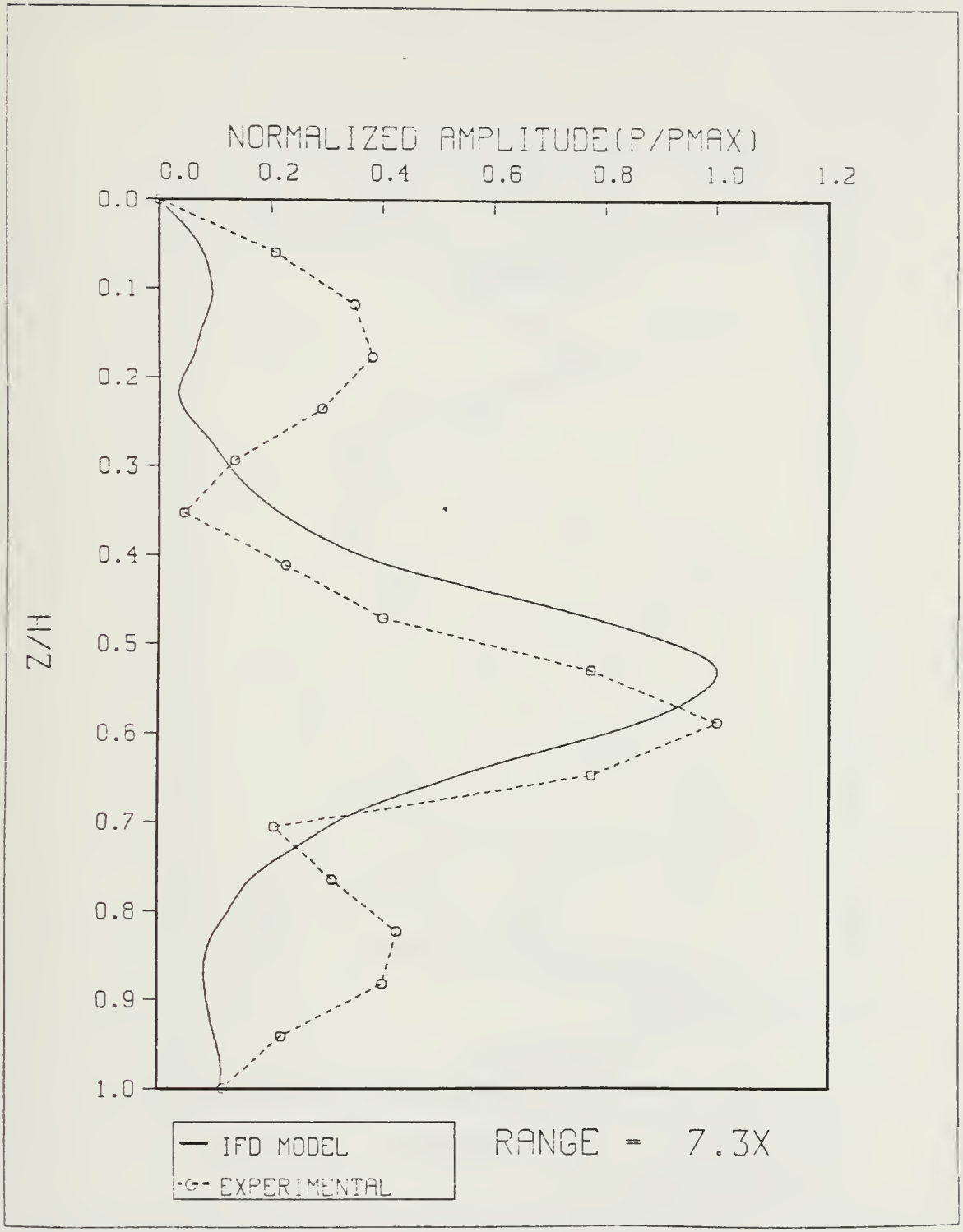


Figure 4.7 Comparison of Results at 7.3X.

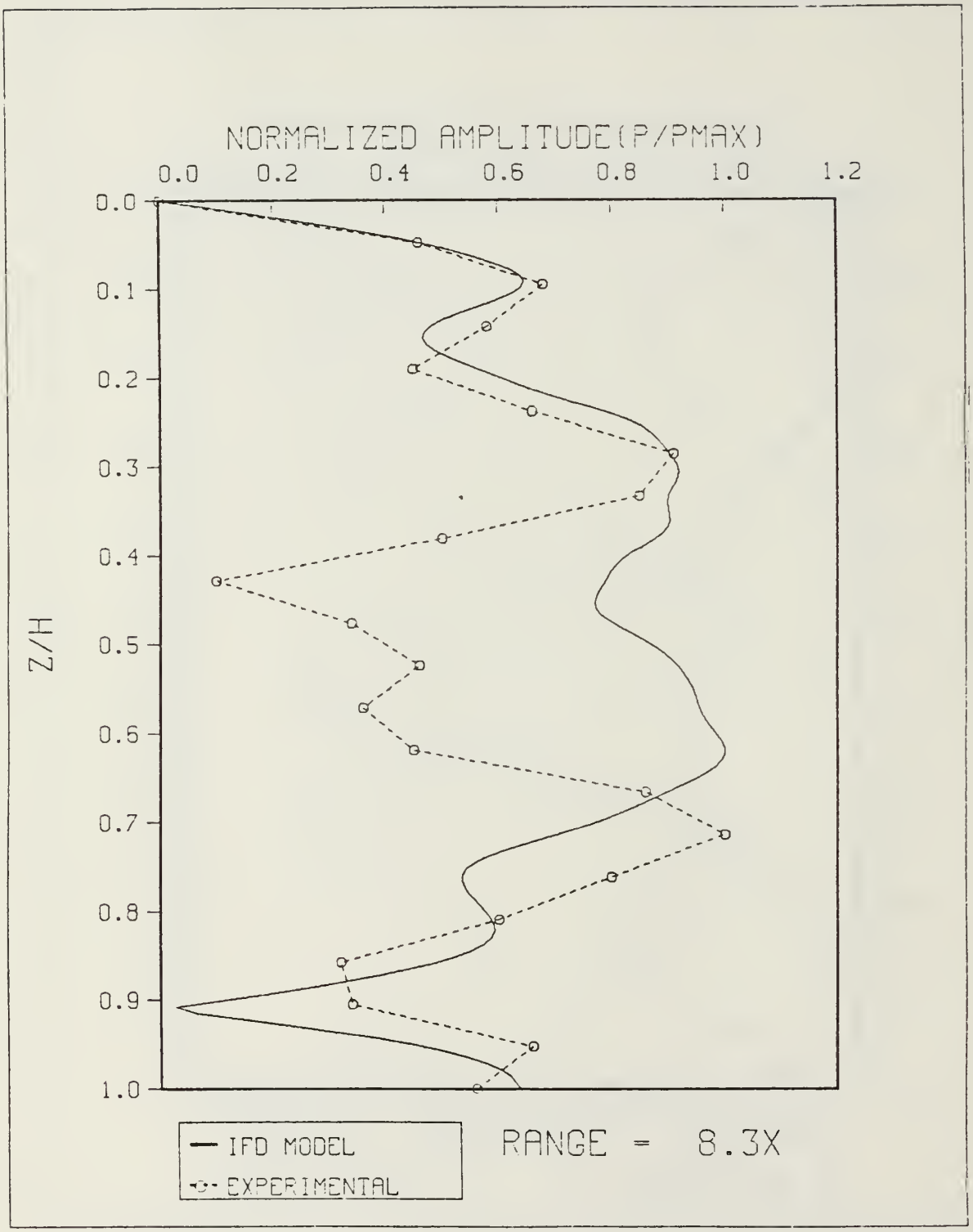


Figure 4.8 Comparison of Results at 8.3X.

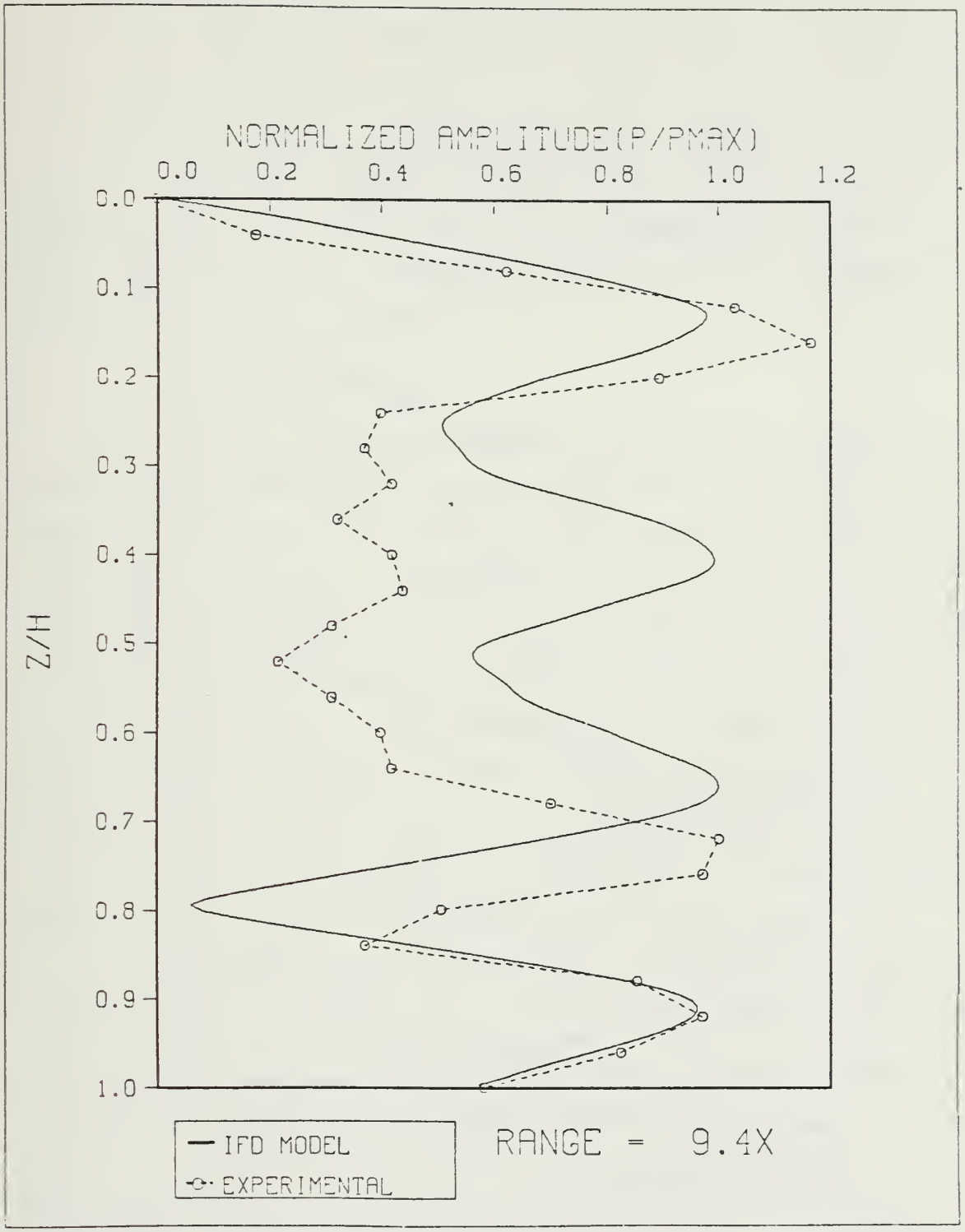


Figure 4.9 Comparison of Results at 9.4X.

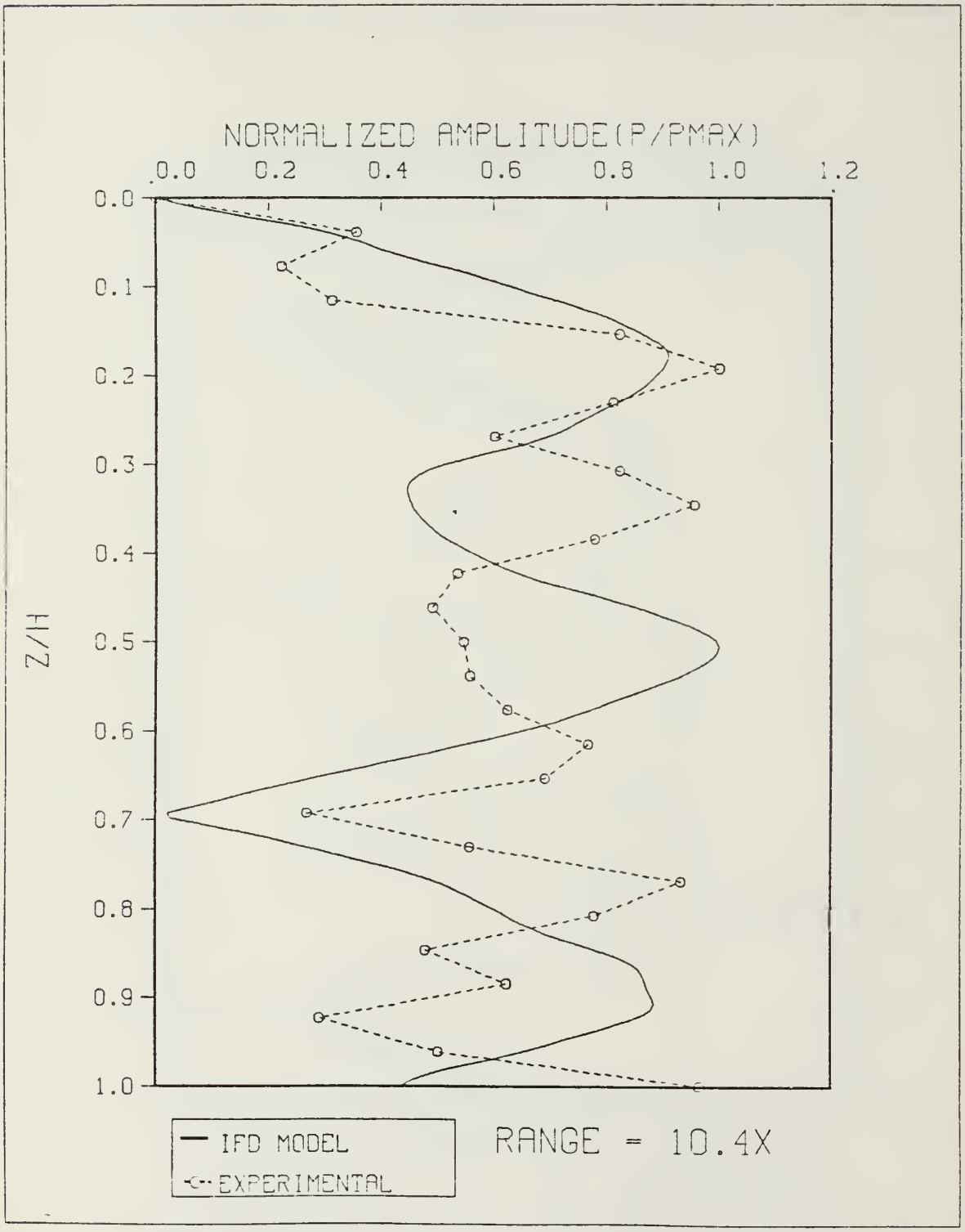


Figure 4.10 Comparison of Results at 10.4X.

In general, the pressure patterns predicted by the IFD and those measured, both become more complicated as the range from the beach increases. At all ranges, there is qualitative agreement in the scale of the predicted features and the scale of the measured features. Quantitative agreement is lacking. This agreement in scale but not detail, suggests that the phases among the normal modes predicted by the model do not accurately reflect the experimental situation.

C. THE DETAILED ANALYSIS

The detailed analysis compared IFD values with experimental measurements every centimeter from 3.0 cm to 11.0 cm from the beach (0.7X to 2.3X). The laboratory measurements were taken by fixing the board at one location and then using the micrometer to adjust the receiver to the desired range. The received CW signal was read from the voltmeter.

These results are depicted in Figures 4.11 through 4.19. In the figures, the IFD predictions are shown as a solid line and the experimental measurements are displayed as circles. Each pressure value was normalized to unity by dividing it by the maximum pressure for the respective curve. The depth values were normalized by dividing each depth by the maximum depth at the particular range.

There is qualitative agreement in the scale of the basic features for all ranges, but quantitative agreement is not observed. The IFD patterns change very little throughout the analysis, while the measured values change more rapidly (especially past 2.0X). The results at 2.1X and 2.3X (Figure 4.18 and Figure 4.19) show that the pressure field can change fairly significantly over a range as short as one centimeter. At those ranges where there is poor agreement between results, there is an indication of phase

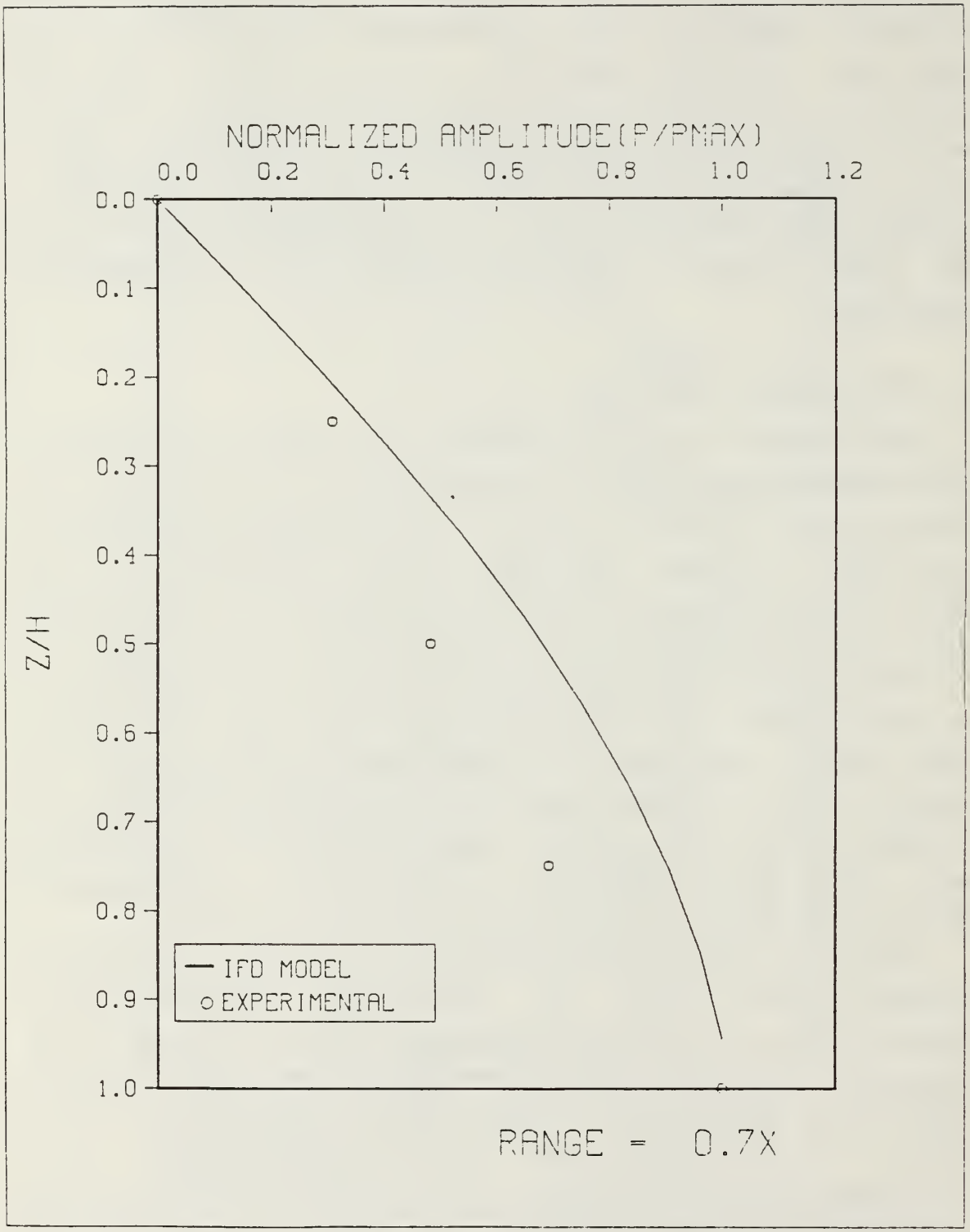


Figure 4.11 Comparison of Results at 0.7X.

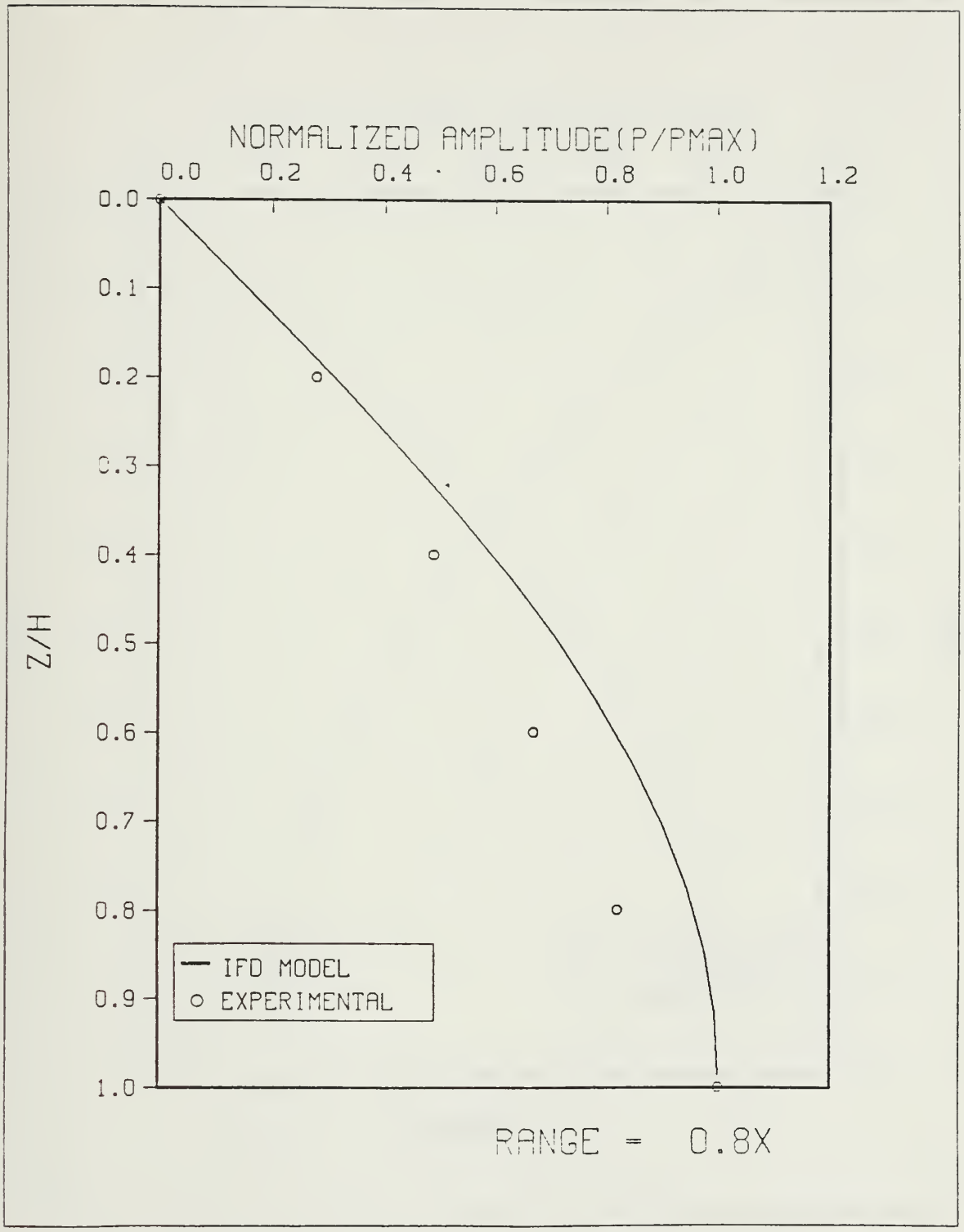


Figure 4.12 Comparison of Results at 0.8X.

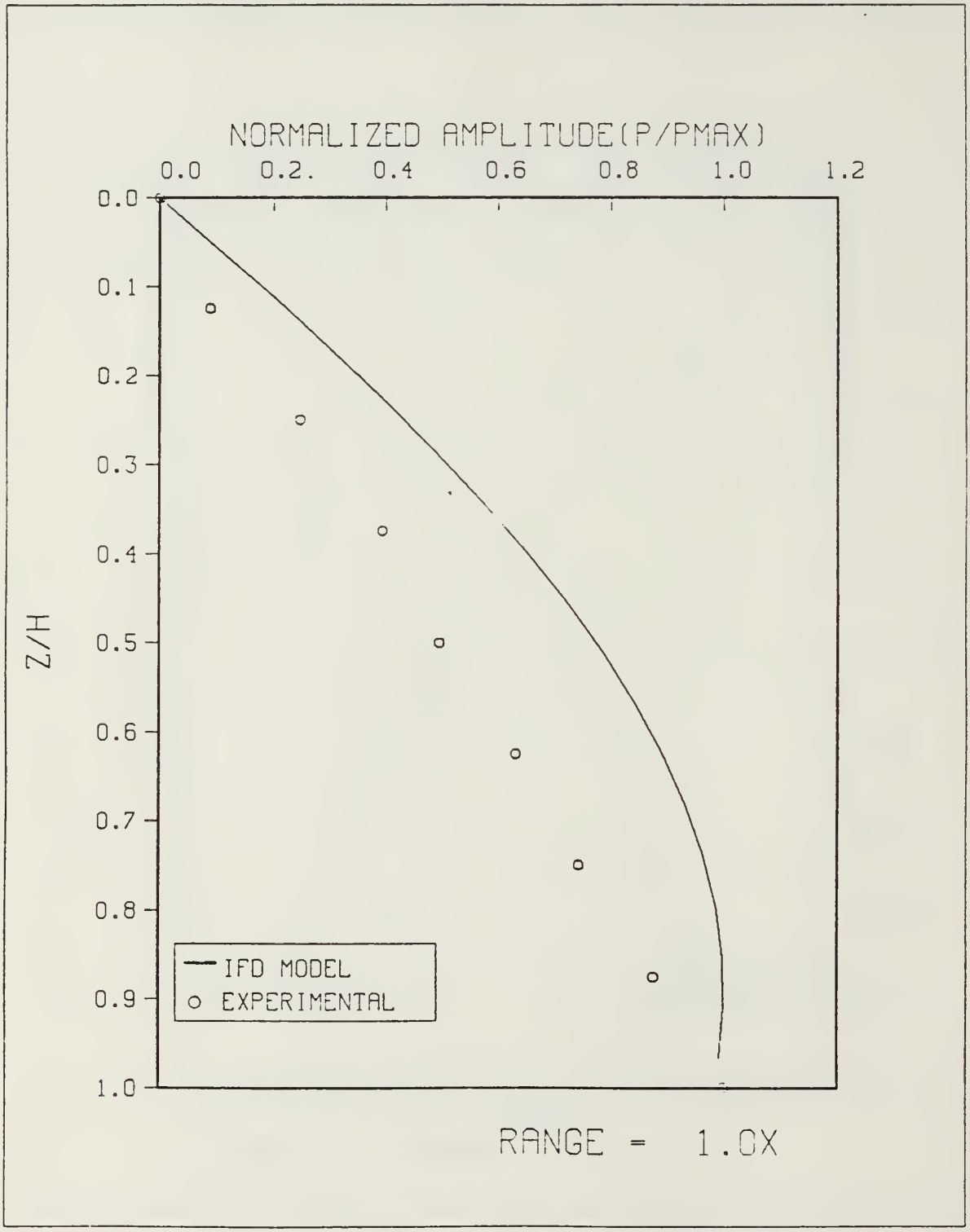


Figure 4.13 Comparison of Results at 1.0X.

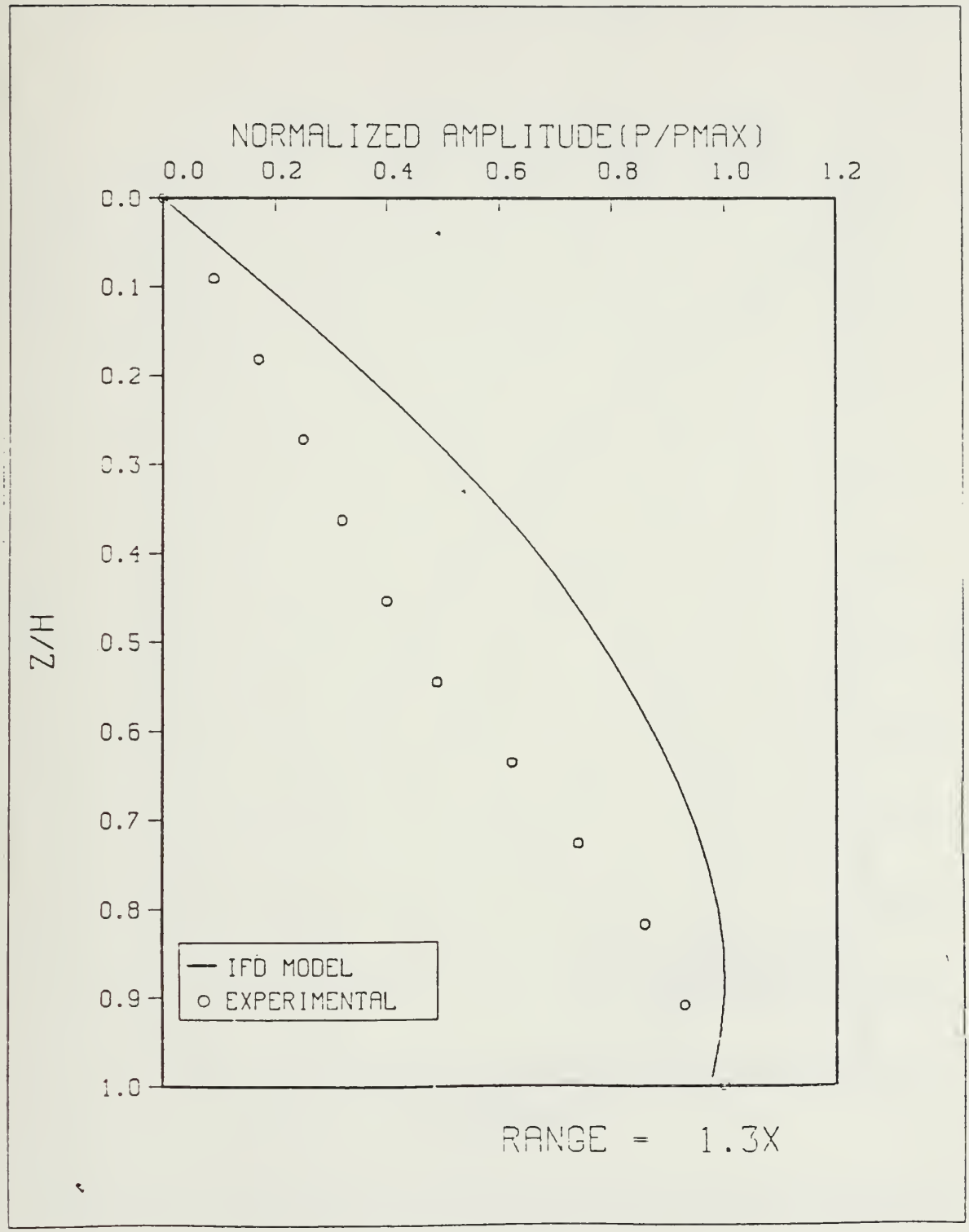


Figure 4.14 Comparisen of Results at 1.3X.

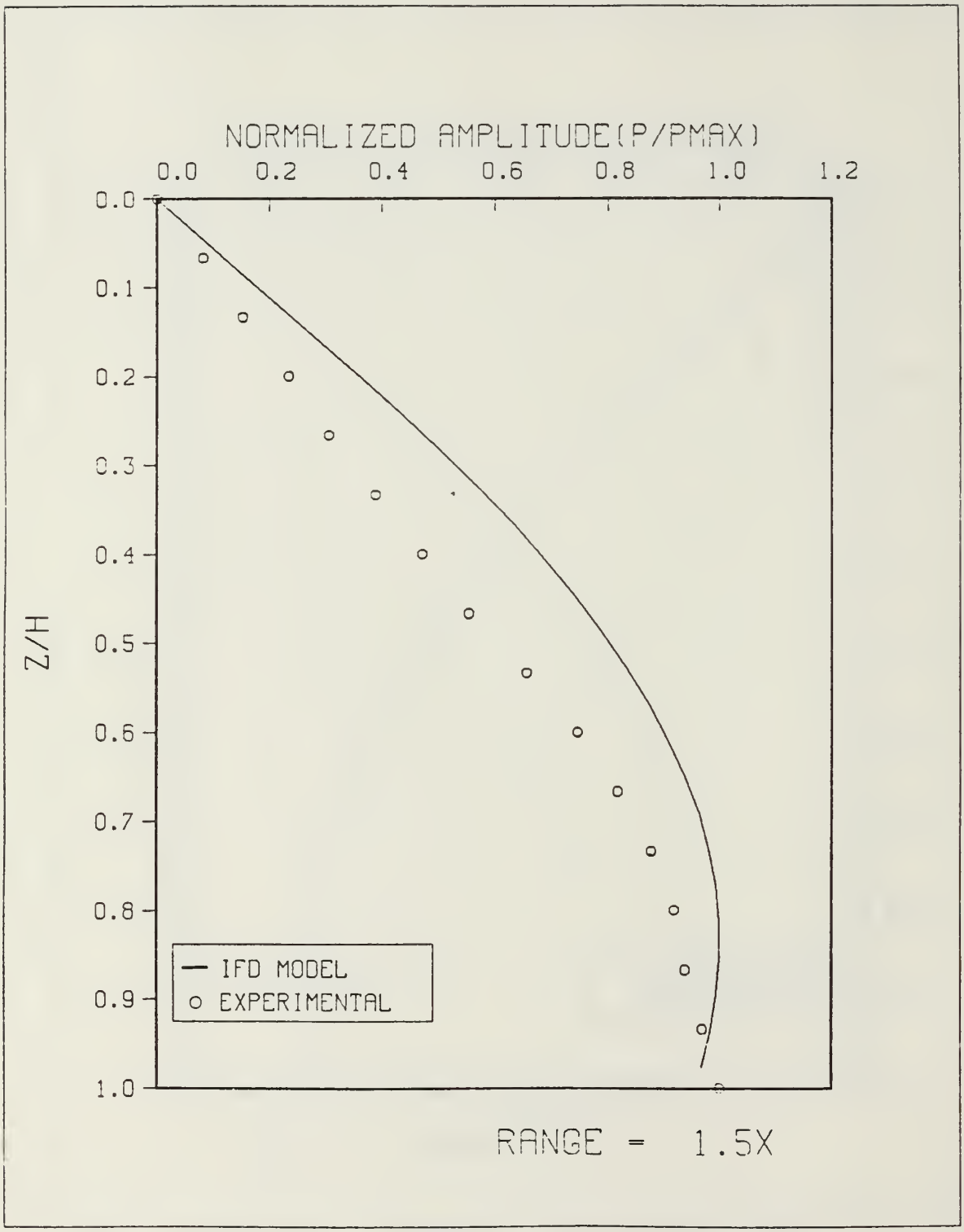


Figure 4.15 Comparison of Results at 1.5X.

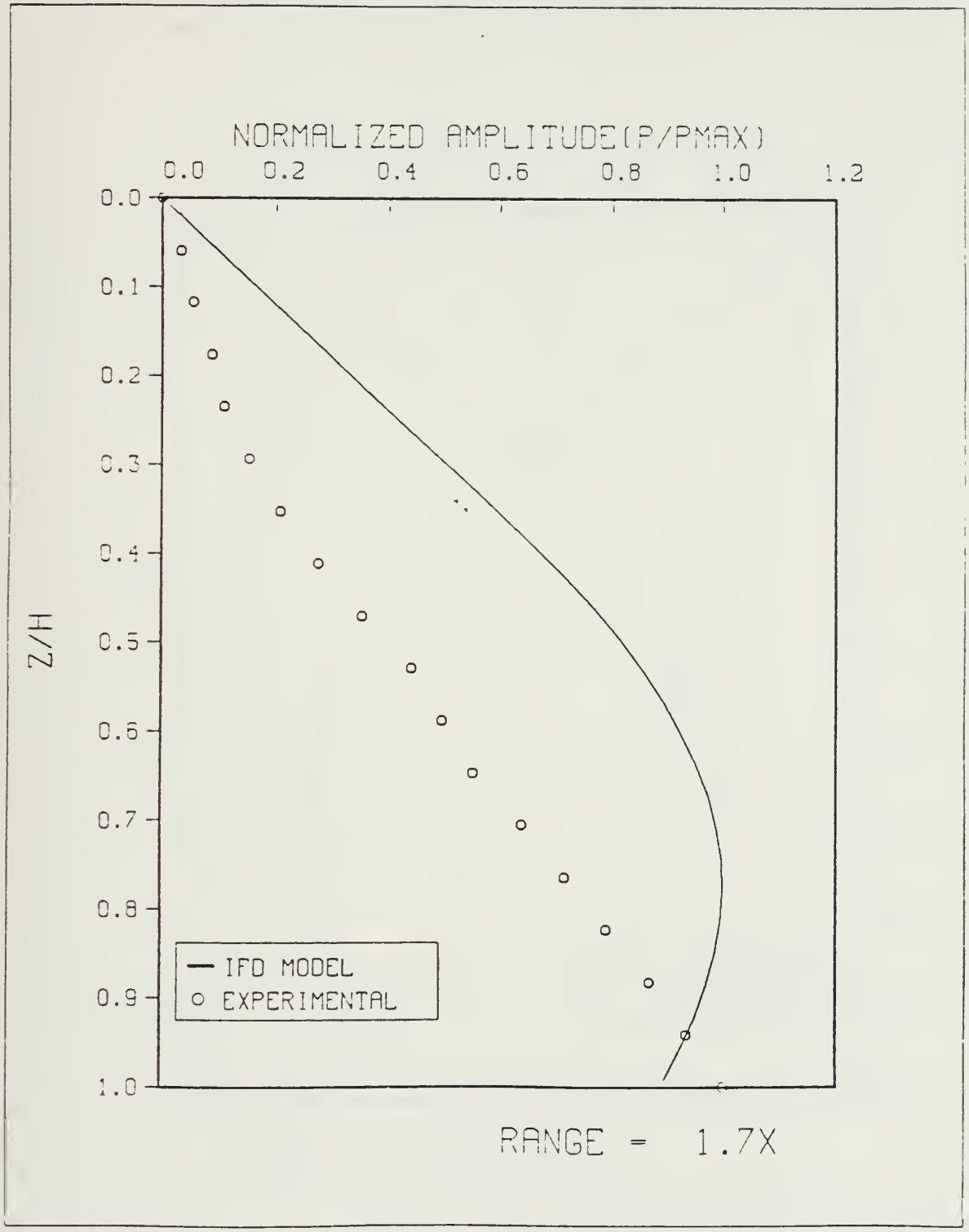


Figure 4.16 Comparison of Results at 1.7X.

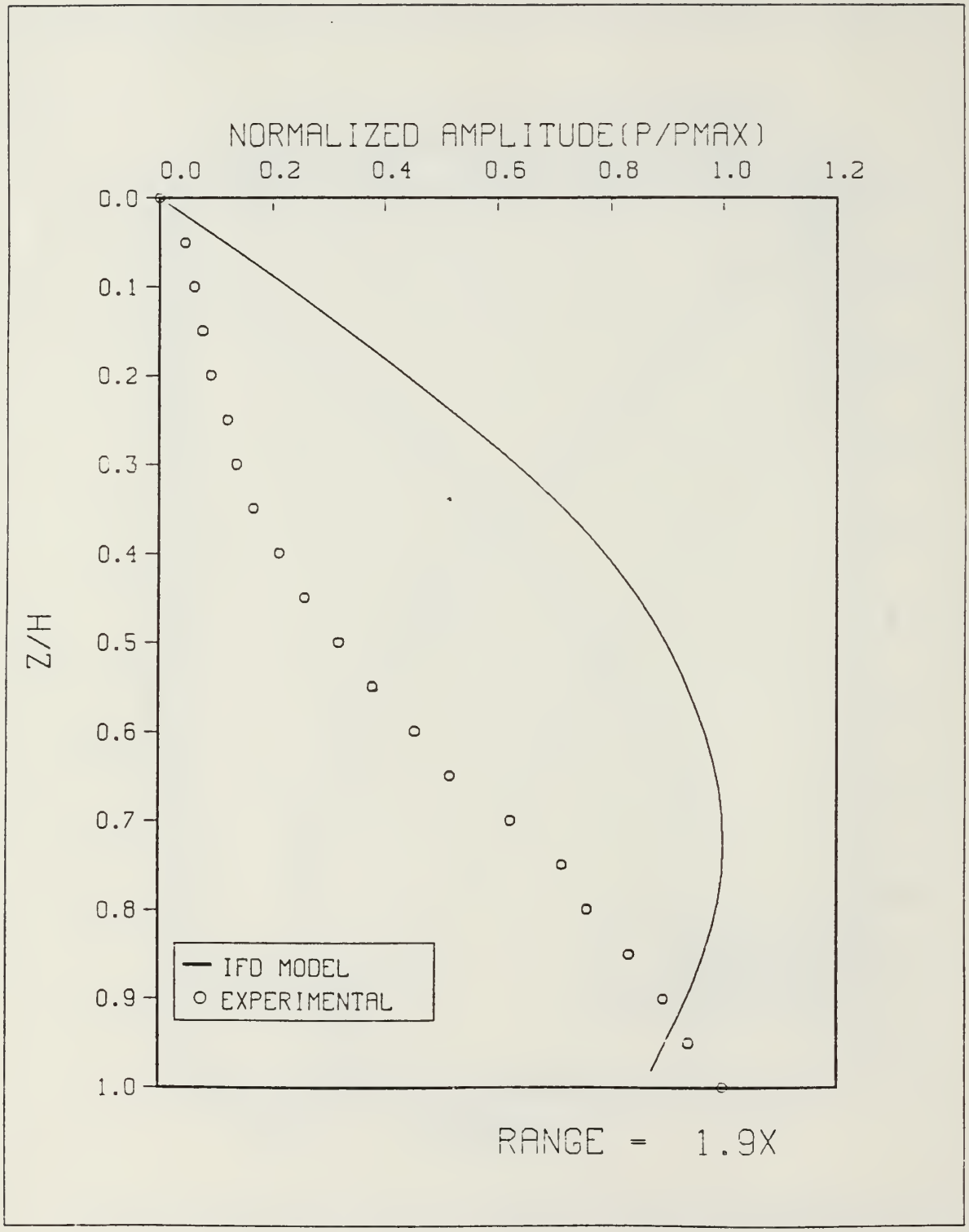


Figure 4.17 Comparison of Results at 1.9X.

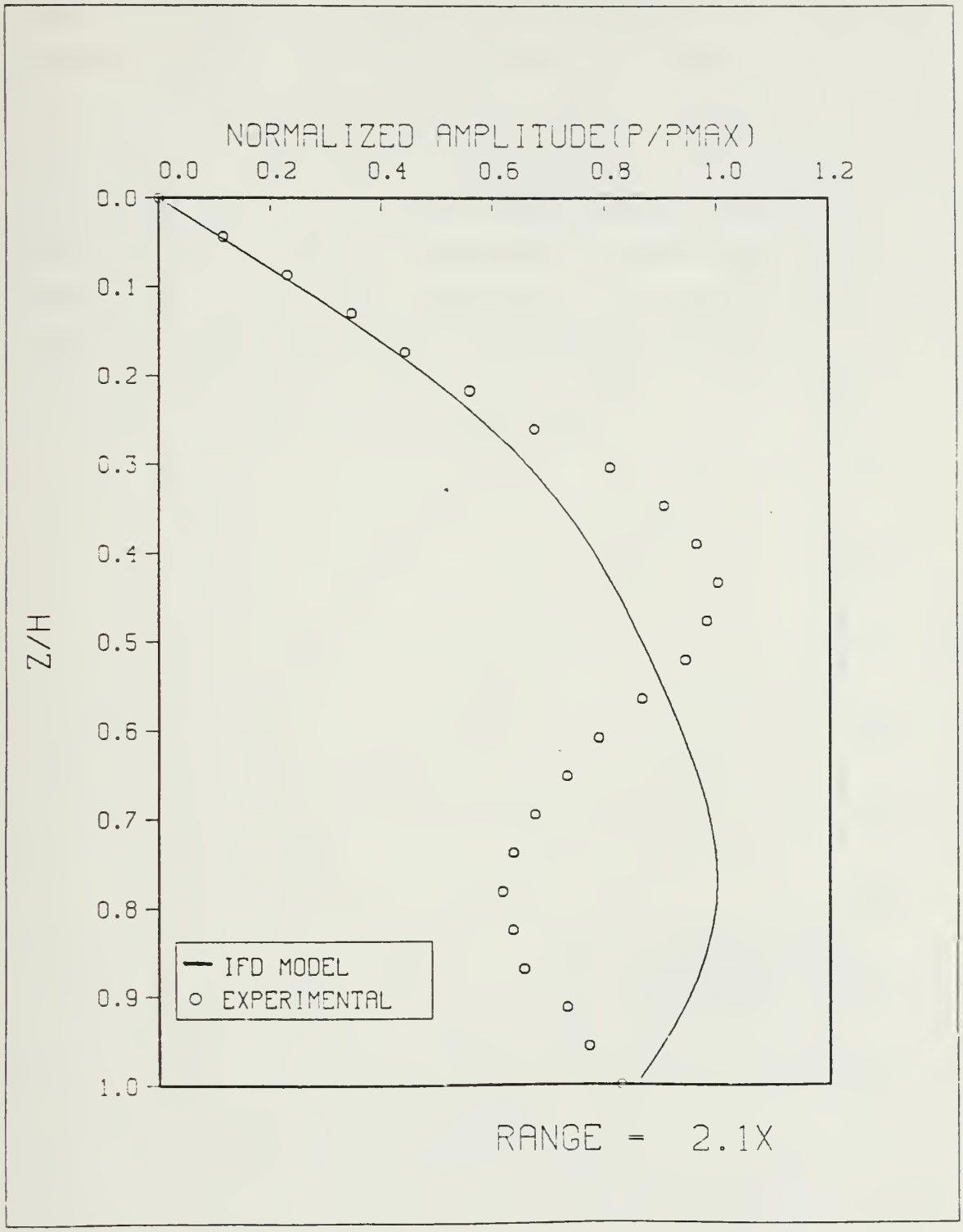


Figure 4.18 Comparison of Results at 2.1X.

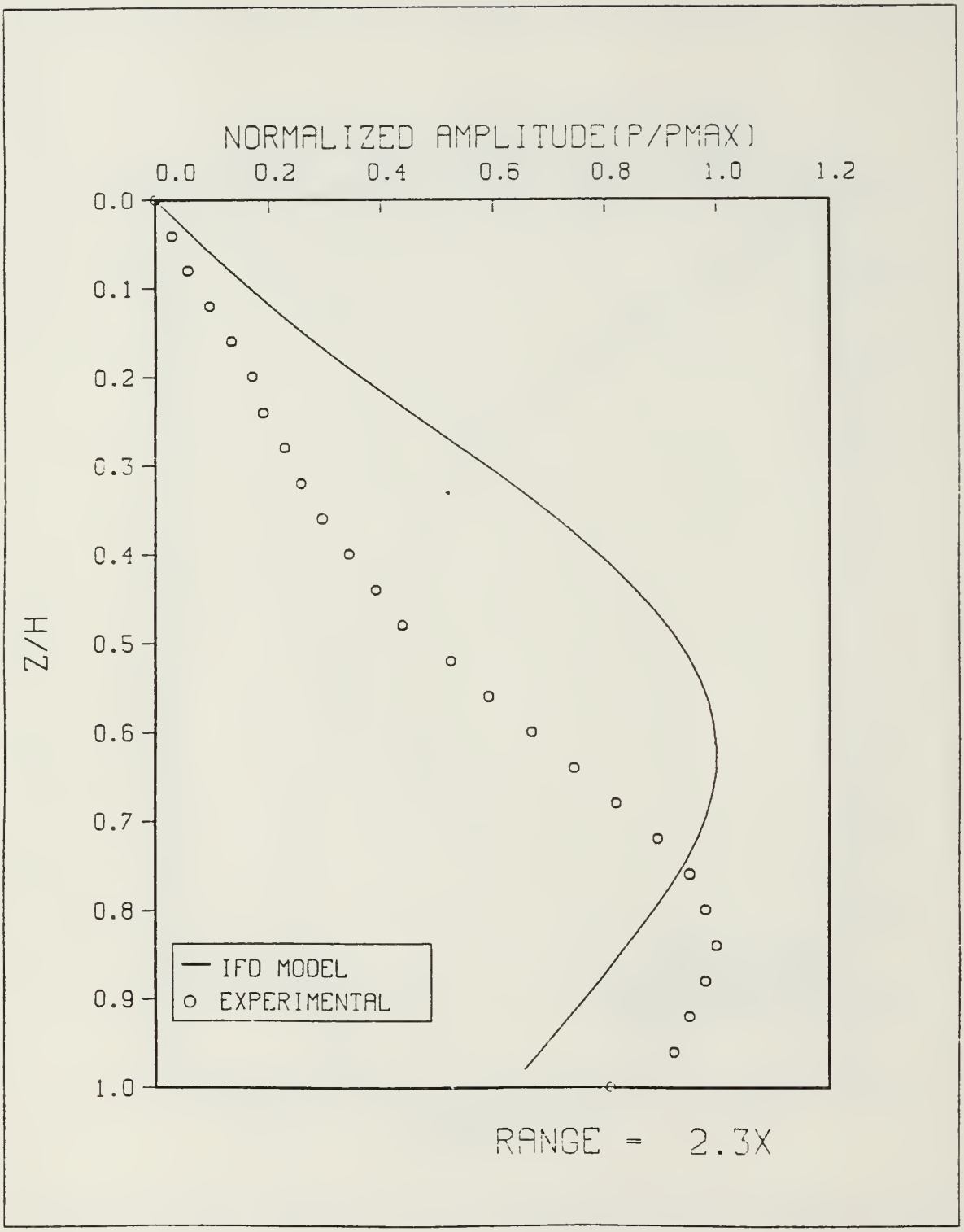


Figure 4.19 Comparison of Results at 2.3X.

interference (Figure 4.18). For distances less than 5X, theory predicts that for a source at mid-depth, the lowest propagating mode should experience interference from only the evanescent tails of higher modes. Therefore, in the region of the detailed analysis, one expects small interference effects. The experimental results in this region however, show rather significant interference. The interference suggests unsuspected propagating modes are present, or that the evanescent tails are larger than expected. From the trend in the curves it appears as if the phase interference is not a factor from 1.5X inward toward the beach (Figures 4.11 through 4.15).

V. CONCLUSIONS/RECOMMENDATIONS

A. CONCLUSIONS

1. Performance of the IFD Model

This analysis of the IFD acoustic model did not uncover any major failures of model performance in a simplified shallow water environment. But this is not to say that the model consistently and accurately performs in such an ocean scenario. Although comparison of IFD predictions with two other models and with simple physical reasoning did not uncover any inconsistencies in performance, the agreement between IFD values and laboratory measurements is insufficient to give complete confidence in the performance of either the model or the experiment.

There is reasonable agreement between the scale of the features predicted by the IFD model and the experiment. Both the model and the measurements show increasing complexity as range is increased from the beach. But despite the similarities, there is poor quantitative agreement in results. One possible cause for the differences may be that the phases of the normal modes predicted by the model are extremely sensitive to minor irregularities in the shape of the interface and the acoustic properties of the bottom. Preliminary work (LeSesne, 1984), suggests that the phase relationships between modes is strongly dependent on the distance of the source from the apex even at great ranges. Consequently, it appears that the collective influence of the normal modes is dependent upon careful geometric control of the experiment.

The detailed analysis around 2X, reveals that large phase interferences occur where only one propagating mode is

expected. This indicates the existence of an extended evanescent tail within cutoff of the higher modes. Kawahara and Isahaya (1978), noted that the apparent phases of the evanescent tails are extremely sensitive to the details of the environment. The results indicate that the tail does not decay quickly, and its influence is pervasive (Figures 4.2 and 4.3). From the trend in the curves, it appears this phase interference is not a factor any closer to the beach than 1.5λ (Figures 4.11 through 4.15).

2. Modeling/Measurement Procedures

The laboratory measurements represent an initial attempt at modeling an idealized shallow water environment. The experimental techniques are not without problems. All sets of measurements were repeated and showed good agreement. The reproducibility of the measurements suggest that random errors have been minimized. However, systematic errors remain which also contribute to the discrepancies between predicted and measured values. Some of these errors derive from equipment, such as the fact that the size of the hydrophone is of the same order of magnitude as the scale of variations in the pressure field. In addition, the environment in the tank may not be sufficiently close to the ideal environment assumed by the model.

E. RECOMMENDATIONS

Further study and verification of the IFD computer model is recommended. A comparison of IFD predictions with other models not analyzed in this study, may uncover the cause of the inconsistency when compared to measured values. A detailed study of the phase interaction of the normal modes, although extremely complex, may also offer insight into the IFD performance.

It appears that the modeling of an idealized shallow water environment in the laboratory is of value in acoustic model verification. Despite the experimental difficulties, there was qualitative agreement in the basic features between model predictions and laboratory measurements. But the experiment represents only an initial probe into the modeling/measurement techniques of a shallow water environment. Further refinement of these techniques and the experimental equipment may result in better quantitative agreement between model predictions and laboratory measurements.

APPENDIX A

REVISED IFD PROGRAM LISTING

```
C     ************************************************************IFD00010
C     ************************************************************IFD00020
C     *  IMPLICIT FINITE-DIFFERENCE PROGRAM FOR                  *IFD00030
C     *  SOLVING THE PARABOLIC EQUATION - REVISED VERSION        *IFD00040
C     ************************************************************IFD00050
C     ************************************************************IFD00060
C     *  LT LARRY JAEGER                                         *IFD00070
C     *  U.S. NAVAL POSTGRADUATE SCHOOL                          *IFD00080
C     *  MONTEREY, CA 93943                                      *IFD00090
C     *  REVISED BY LT MARK E. KOSNIK (JUNE 1984)                *IFD00100
C     ************************************************************IFD00110
C     ************************************************************IFD00120
C     ************************************************************IFD00130
C     ****  A IMPLICIT LIST OF PROGRAM VARIABLES FOLLOWS:       ****IFD00140
C     ************************************************************IFD00150
C     ***  A     - ARRAY - COEFFICIENT A IN PARABOLIC EQUATION    IFD00160
C                    (IN WATER)                                    IFD00170
C     ***  A2    - COEFFICIENT A IN PARABOLIC EQUATION (IN SEDIMENT)IFD00180
C     ***  ALPHA - VOLUME ATTENUATION - DB/METER                  IFD00190
C     ***  ATT   - ARRAY - ATTENUATION COEFFICIENT FOR ARTIFICIAL IFD00200
C                    ATTENUATION LAYER                             IFD00210
C     ***  BETA1 - BETA 1 AS DEFINED IN LEE AND MCDANIEL (1983)   IFD00220
C     ***  BETA2 - BETA 2 AS DEFINED IN LEE AND MCDANIEL (1983)   IFD00230
C     ***  BETA1 - ATTENUATION IN WATER - DB/WAVELENGTH           IFD00240
C     ***  BETA2 - ATTENUATION IN SEDIMENT - DB/WAVELENGTH        IFD00250
C     ***  BK    - ARRAY - RANGE FOR BOTTOM PROFILE - METERS      IFD00260
C     ***  BZ    - ARRAY - DEPTH FOR BOTTOM PROFILE - METERS      IFD00270
C     ***  C     - ARRAY - CONTAINS TRIDIAGONAL MATRIX SYSTEM THAT NEEDS IFD00280
C                    TO BE SOLVED (SEE SUBROUTINE TRIDG)           IFD00290
C     ***  C0    - REFERENCE SOUND SPEED - METERS/SEC             IFD00300
C     ***  C2    - SOUND SPEED IN SEDIMENT                        IFD00310
C     ***  CCSE  - COS(THETA)                                     IFD00320
C     ***  CK    - ARRAY - STORAGE SPACE USED IN SUBROUTINES TRIDG AND IFD00330
C                    TRIAL                                         IFD00340
C     ***  CSVP  - ARRAY - SOUND SPEED IN SOUND SPEED PROFILE -   IFD00350
C                    METERS/SEC                                    IFD00360
C     ***  CTWO  - ARRAY - STORAGE SPACE USED IN SUBROUTINES TRIDG AND IFD00370
C                    TRIAL                                         IFD00380
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C      *** CWATER- ARRAY - SOUND SPEED AT GRID POINTS IN WATER COLUMN     IFD00390
C      *** DELTA - DELTA AS DEFINED IN LEE AND MCDANIEL (1983)           IFD00400
C      *** DELIN - 1 / DELTA                                             IFD00410
C      *** DIFD  - ARRAY - STORAGE SPACE FOR TI VALUES USED TO CONTOUR   IFD00420
C                  PLOT                                                 IFD00430
C      *** DR    - RANGE STEP - METERS                                   IFD00440
C      *** DRLVL - RANGE STEP ALONG LEVEL INTERFACE - METERS             IFD00450
C      *** DRMAX - MAXIMUM ALLOWABLE RANGE STEP - METERS                 IFD00460
C      *** DZ    - DEPTH INCREMENT OF SOLUTION - METERS                  IFD00470
C      *** EYE   - COMPLEX "I"                                           IFD00480
C      *** FRQ   - FREQUENCY - HZ                                        IFD00490
C      *** GAMMA1- GAMMA 1 AS DEFINED IN LEE AND MCDANIEL (1983)         IFD00500
C      *** GAMMA2- GAMMA 2 AS DEFINED IN LEE AND MCDANIEL (1983)         IFD00510
C      *** IBOT1 - POINTER THAT POINTS TO BOTTOM PROFILE POINT AT START  IFD00520
C                  OF BOTTOM SEGMENT                                    IFD00530
C      *** IBOT2 - POINTER THAT POINTS TO BOTTOM PROFILE POINT AT END    IFD00540
C                  OF BOTTOM SEGMENT                                    IFD00550
C      *** ID    - ARRAY - RUN IDENTIFICATION                            IFD00560
C      *** IFACE - POINTER THAT POINTS TO INTERFACE AT RANGE RA1          IFD00570
C      *** IFACE2- POINTER THAT POINTS TO INTERFACE AT RANGE RA2          IFD00580
C      *** IFACEM- IFACE - 1                                             IFD00590
C      *** IFACEP- IFACE + 1                                             IFD00600
C      *** II    - COUNTER INDEX FOR DEPTH VALUES                        IFD00610
C      *** IPZ   - EVERY IPZ'TH VALUE IN DEPTH IS PRINTED                IFD00620
C      *** IR    - COUNTER INDEX FOR RANGE VALUES                        IFD00630
C      *** ISLOPE- SLOPE FLAG:                                           IFD00640
C                  ISLOPE = 1  -  BOTTOM SLOPES DOWN                    IFD00650
C                  ISLOPE = 2  -  BOTTOM LEVEL                          IFD00660
C                  ISLOPE = 3  -  BOTTOM SLOPES UP                      IFD00670
C                  ISLOPE = 4  -  BOTTOM SLOPES DOWN, BOTTOM MODIFIED   IFD00680
C                  ISLOPE = 5  -  BOTTOM SLOPES UP, BOTTOM MODIFIED     IFD00690
C      *** ITEMP - TEMPORARY VARIABLE                                    IFD00700
C      *** IWZ   - GRID POINT CORRESPONDING TO RECEIVER DEPTH            IFD00710
C      *** N     - NUMBER OF EQUI-SPACED GRID POINTS IN U                IFD00720
C                - INCLUDES BOTTOM POINT - DOES NOT INCLUDE SURFACE POINTIFD00730
C      *** NA    - NUMBER OF POINTS IN ARTIFICIAL ATTENUATION LAYER      IFD00740
C      *** NBOT  - NUMBER OF POINTS IN BOTTOM PROFILE (BR AND BZ)        IFD00750
C      *** NIU   - UNIT NUMBER FOR INPUT DATA                            IFD00760
C      *** NM1   - N - 1                                                 IFD00770
C      *** NOU   - UNIT NUMBER FOR OUTPUT PLOTTER FILE                   IFD00780
C      *** NPOUT - UNIT NUMBER FOR OUTPUT PRINTER FILE                   IFD00790
C      *** NSTEP - NUMBER OF RANGE STEPS ALONG A BOTTOM SEGMENT          IFD00800
C      *** NSTEP1- NUMBER OF RANGE STEPS CORRESPONDING TO ONE VERTICAL   IFD00810
C                  GRID STEP FOR MODIFIED BOTTOM                        IFD00820
C      *** NSVP  - NUMBER OF POINTS IN CSVP AND ZSVP                     IFD00830
C      *** NWMAX - NUMBER OF GRID POINTS IN WATER AT MAX DEPTH           IFD00840
C      *** NXLFS - NUMBER OF NEXT LEVEL SECTION FOLLOWING A SLOPING      IFD00850
C                  SECTION FOR A MODIFIED BOTTOM                        IFD00860
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C      *** PDR    - RANGE INCREMENT AT WHICH SOLUTION IS PASSED TO          IFD00870
C                   OUTPUT PRINTER FILE - METERS                           IFD00880
C      *** PDZ    - DEPTH INCREMENT AT WHICH SOLUTION IS PRINTED - METERS  IFD00890
C      *** PI     - THE VALUE OF PI                                        IFD00900
C      *** PL     - PROPAGATION LOSS - DB                                  IFD00910
C      *** PRMAG  - ARRAY - MAGNITUDE OF REAL AND IMAGINARY PRESSURE       IFD00920
C      *** R1     - RANGE AT WHICH BOTTOM DEPTH IS AVAILABLE - METERS      IFD00930
C      *** R2     - NEXT RANGE AT WHICH BOTTOM DEPTH IS AVAILABLE - METERS IFD00940
C                   - INCREMENTED AS SOLUTION IS MARCHED OUT IN RANGE.      IFD00950
C      *** RA1    - RANGE AT WHICH SOLUTION IS KNOWN - METERS              IFD00960
C      *** RA2    - RANGE AT WHICH SOLUTION IS TO BE SOLVED - METERS       IFD00970
C                   ( RA2 = RA1 + DR )                                     IFD00980
C      *** RHO1   - DENSITY IN WATER - GM/CM**3                            IFD00990
C      *** RHO2   - DENSITY IN SEDIMENT - GM/CM**3                         IFD01000
C      *** RMAX   - MAXIMUM RANGE OF SOLUTION - METERS                     IFD01010
C      *** SINE   - SIN ( THETA )                                          IFD01020
C      *** TEMP   - TEMPORARY VARIABLE                                     IFD01030
C      *** THETA  - SLOPE OF BOTTOM - RADIANS                              IFD01040
C                   THETA = 0   -  LEVEL INTERFACE                         IFD01050
C                   THETA > 0   -  INTERFACE SLOPES DOWN                   IFD01060
C                   THETA < 0   -  INTERFACE SLOPES UP                     IFD01070
C      *** U      - ARRAY - COMPLEX ACOUSTIC PRESSURE FIELD                IFD01080
C      *** WDR    - RANGE STEP AT WHICH SOLUTION IS WRITTEN TO OUTPUT      IFD01090
C                   PLOTTER FILE                                           IFD01100
C      *** XK0    - REFERENCE WAVE NUMBER                                  IFD01110
C      *** XII    - MATRIX ELEMENT, X MATRIX, LOWER DIAGONAL, ON INTERFACE IFD01120
C      *** XIIZ   - XII FOR SLOPING BOTTOM                                 IFD01130
C      *** XLAMDA - REFERENCE WAVELENGTH - METERS                          IFD01140
C      *** XIRWS  - MATRIX ELEMENT, X MATRIX, OFF-DIAGONAL, IN WATER AND   IFD01150
C                   SEDIMENT                                               IFD01160
C      *** XMI    - MATRIX ELEMENT, X MATRIX, MAIN DIAGONAL, ON INTERFACE  IFD01170
C      *** XMS    - MATRIX ELEMENT, X MATRIX, MAIN DIAGONAL, IN SEDIMENT   IFD01180
C      *** XMW    - ARRAY - MATRIX ELEMENT, X MATRIX, MAIN DIAGONAL, IN    IFD01190
C                   WATER                                                  IFD01200
C      *** XN     - REAL INDEX OF REFRACTION                               IFD01210
C      *** XN1    - COMPLEX INDEX OF REFRACTION SQUARED                    IFD01220
C      *** XPR    - RANGE AT WHICH SOLUTION IS PRINTED - METERS            IFD01230
C      *** XWR    - RANGE AT WHICH SOLUTION IS WRITTEN TO OUTPUT           IFD01240
C                   PLOTTER FILE                                           IFD01250
C      *** XX...  - VARIABLES THAT BEGIN WITH XX HAVE NO SPECIAL PHYSICAL   IFD01260
C                   SIGNIFICANCE BUT THEY CONTRIBUTE TO COMPUTATIONAL      IFD01270
C                   EFFICIENCY.  ALL XX VARIABLES ARE CALCULATED IN        IFD01280
C                   SUBROUTINE INITAL, ALL ARE INDEPENDENT OF RANGE STEP   IFD01290
C                   AND INTERFACE SLOPE, AND ALL ARE USED TO CALCULATE     IFD01300
C                   MATRIX ELEMENTS.                                       IFD01310
C      *** YII    - MATRIX ELEMENT, Y MATRIX, LOWER DIAGONAL, ON INTERFACE IFD01320
C      *** YIIV   - YII FOR LEVEL INTERFACE                                IFD01330
C      *** YIIZ   - YII FOR SLOPING INTERFACE                              IFD01340
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C     *** YIRWS - MATRIX ELEMENT, Y MATRIX, OFF-DIAGONAL, IN WATER AND  IFD01350
C                 SEDIMENT                                              IFD01360
C     *** YMI   - MATRIX ELEMENT, Y MATRIX, MAIN DIAGONAL, ON INTERFACE IFD01370
C     *** YMS   - MATRIX ELEMENT, Y MATRIX, MAIN DIAGONAL, IN SEDIMENT  IFD01380
C     *** YMW   - ARRAY - MATRIX ELEMENTS, Y MATRIX, MAIN DIAGONAL, IN  IFD01390
C                 WATER                                                 IFD01400
C     *** YRI   - MATRIX ELEMENT, Y MATRIX, UPPER DIAGONAL, ON INTERFACEIFD01410
C     *** YRIV  - YRI FOR LEVEL INTERFACE                               IFD01420
C     *** YRIZ  - YRI FOR SLOPING INTERFACE                             IFD01430
C     *** Z1    - DEPTH OF WATER AT RANGE R1 - METERS                   IFD01440
C     *** Z2    - DEPTH OF WATER AT RANGE R2 - METERS                   IFD01450
C     *** ZABLYR- DEPTH OF UPPER EDGE OF ARTIFICIAL ATTENUATION         IFD01460
C                 LAYER - METERS                                        IFD01470
C     *** ZI    - DEPTH OF GRID POINT - METERS                          IFD01480
C     *** ZIYR1 - MAXIMUM WATER DEPTH - METERS                          IFD01490
C     *** ZIYR2 - DEPTH OF PRESSURE RELEASE SURFACE - METERS            IFD01500
C     *** ZR    - RECEIVER DEPTH - METERS                               IFD01510
C     *** ZS    - SOURCE DEPTH - METERS                                 IFD01520
C     *** ZSVP  - ARRAY - DEPTH FOR SOUND SPEED PROFILE - METERS        IFD01530
C     *** ZZ... - VARIABLES THAT BEGIN WITH ZZ HAVE NO SPECIAL PHYSICAL IFD01540
C                 SIGNIFICANCE BUT THEY CONTRIBUTE TO COMPUTATIONAL     IFD01550
C                 EFFICIENCY.  ALL ZZ VARIABLES ARE CALCULATED IN       IFD01560
C                 SUBROUTINE NEWMAT, ALL DEPEND ON RANGE STEP AND/OR    IFD01570
C                 INTERFACE SLOPE, AND ALL ARE USED TO CALCULATE MATRIX IFD01580
C                 ELEMENTS.                                             IFD01590
C     ************************************************************    IFD01600
C     *** INPUT                                                         IFD01610
C     ************************************************************    IFD01620
C     INPUT UNIT NUMBER = NIU                                           IFD01630
C     INPUT FILENAME AND FILETYPE = IFDIN DATAIN                        IFD01640
C     CONTENTS:  CARD IMAGES IN FREE FORMAT                             IFD01650
C       CARD 1     :  FRQ, ZS, ZR, C0, N                                IFD01660
C       CARD 2     :  RMAX, DRIVL, DRMAX, WDR, PDR, PDZ                 IFD01670
C       CARD 3     :  R(1), BZ(1)        **                             IFD01680
C       CARD 4     :  R(2), BZ(2)          *    BOTTOM PROFILE         IFD01690
C          .          .                    **   RANGE, WATER DEPTH (METERS)IFD01700
C          .          .                    *                           IFD01710
C       CARD N     :  .                  **                             IFD01720
C       CARD N+1   :  -1, -1                                            IFD01730
C       CARD N+2   :  ZIYR1, RHO1, BETA1                                IFD01740
C       CARD N+3   :  ZSVP(1),CSVP(1)     **                            IFD01750
C       CARD N+4   :  ZSVP(2),CSVP(2)       *   SOUND SPEED PROFILE   IFD01760
C          .          .        .              **  DEPTH (METERS) AND SOUND IFD01770
C          .          .        .              *   SPEED (METERS/SEC)    IFD01780
C       CARD N+M   :  ZSVP(J),CSVP(J)     **                            IFD01790
C       CARD N+M+1 :  ZIYR2, RHO2, BETA2, C2                            IFD01800
C       CARD N+M+2 :  ZABLYR                                            IFD01810
C                                                                       IFD01820
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C          WHERE:                                                                IFD01830
C             FRQ     = FREQUENCY (HZ)                                           IFD01840
C             ZS      = SOURCE DEPTH (M)                                         IFD01850
C             ZR      = RECEIVER DEPTH (M)                                       IFD01860
C             C0      = REFERENCE SOUND SPEED (M/S). IF C0 = 0.0, C0 IS          IFD01870
C                       SET TO AVERAGE SOUND SPEED IN WATER COLUMN.              IFD01880
C             N       = NUMBER OF GRID POINTS                                    IFD01890
C                                                                                IFD01900
C             RMAX    = MAXIMUM RANGE (M) OF SOLUTION                            IFD01910
C             DRLVL   = RANGE STEP (M) ALONG LEVEL INTERFACE. IF                 IFD01920
C                       DRLVL = 0.0, DRLVL SET TO 1/2 WAVELENGTH. IF             IFD01930
C                       DRLVL GREATER THAN DRMAX, DRLVL SET TO DRMAX.            IFD01940
C             DRMAX   = MAXIMUM ALLOWABLE RANGE STEP (M). IF DRMAX = 0.0,        IFD01950
C                       DRMAX IS SET TO ONE WAVELENGTH.                          IFD01960
C             WDR     = RANGE STEP (M) AT WHICH SOLUTION IS  WRITTEN TO          IFD01970
C                       FILE USED BY PLOTTING ROUTINE.                           IFD01980
C                       ROUNDED TO NEAREST DR.                                   IFD01990
C             PDR     = RANGE STEP (M) AT WHICH SOLUTION IS PRINTED.             IFD02000
C                       ROUNDED TO NEAREST DR.                                   IFD02010
C             PDZ     = DEPTH INCREMENT AT WHICH SOLUTION IS PRINTED.            IFD02020
C                       ROUNDED TO NEAREST DZ.                                   IFD02030
C                                                                                IFD02040
C             BR      = RANGE (M) OF BOTTOM PROFILE                              IFD02050
C             BZ      = DEPTH (M) OF BOTTOM PROFILE                              IFD02060
C                                                                                IFD02070
C             ZLYR1   = MAXIMUM WATER DEPTH (M)                                  IFD02080
C             RHO1    = DENSITY IN WATER (GM/CM**3)                              IFD02090
C             BETA1   = ATTENUATION (DB/WAVELENGTH) IN WATER.  IF BETA1          IFD02100
C                       NEGATIVE THEN ATTENUATION COMPUTED.                      IFD02110
C                                                                                IFD02120
C             ZSVP    = DEPTH (M) ARRAY FOR SOUND SPEED PROFILE                  IFD02130
C             CSVP    = SOUND SPEED (M/S) ARRAY FOR SOUND SPEED PROFILE          IFD02140
C                                                                                IFD02150
C             ZLYR2   = DEPTH (M) OF PRESSURE RELEASE SURFACE                    IFD02160
C             RHO2    = DENSITY (GM/CM**3) IN SEDIMENT                           IFD02170
C             BETA2   = ATTENUATION (DB/WAVELENGTH) IN SEDIMENT                  IFD02180
C             C2      = SOUND SPEED (M/S) IN SEDIMENT                            IFD02190
C                                                                                IFD02200
C             ZAELYR  = DEPTH (M) OF UPPER SURFACE OF ARTIFICIAL                 IFD02210
C                       ATTENUATION LAYER                                        IFD02220
C                                                                                IFD02230
C     ***************************************************************************IFD02240
C     *** OUTPUT                                                                 IFD02250
C     ***************************************************************************IFD02260
C         OUTPUT UNIT NUMBER FOR FILE USED BY PLOTTING ROUTINE = NOU             IFD02270
C         FILENAME AND FILETYPE FOR OUTPUT PLOTTER FILE = IFDOUT PLOTTER         IFD02280
C                                                                                IFD02290
C         OUTPUT UNIT NUMBER FOR PRINT FILE = NPOUT                              IFD02300
```

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C          FILENAME AND FILETYPE FOR OUTPUT PRINTER FILE = IFDCUT PRINTER  IFD02310
C     ********************************************************************IFD02320
C                                                                          IFD02330
      COMPLEX A,A2,C,CR,CTWO,EYE,                                          IFD02340
     *        XL1,XL12,XLRWS,XMI,XMS,XRI,XRIZ,                             IFD02350
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,                   IFD02360
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,               IFD02370
     *        U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                   IFD02380
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBCT,NM1,       IFD02390
     *        NSTEP,NSTEP1,NSVP,NWMAX,NXLFS,IR                             IFD02400
      COMMON /REAL/ AIPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,        IFD02410
     *        CSVP(101),C2,CWATER(5000),DR,DRLVL,DRMAX,EZ,FRQ,PDR,PDZ,     IFD02420
     *        R1,RA1,RA2,RHO1,RHO2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,     IFD02430
     *        XX11,XWR,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR,             IFD02440
     *        PIFD(121,121)                                                IFD02450
      COMMON /CPLX/  A(5000),A2,C(5000,4),CR(5000),CTWO(5000),             IFD02460
     *        EYE,XL1,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                         IFD02470
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),             IFD02480
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,         IFD02490
     *        U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                             IFD02500
      IR = 0                                                               IFD02510
C                                                                          IFD02520
C     *** THE FOLLOWING CALL IS REQUIRED FOR THE NPS IBM COMPUTER.         IFD02530
C     *** IT PERMITS CONTINUED EXECUTION FOR ANY NUMBER OF UNDERFLOW       IFD02540
C     *** "ERRORS"                                                         IFD02550
          CALL ERRSET (208,300,-1,1,1)                                     IFD02560
C                                                                          IFD02570
      CALL READ                                                            IFD02580
      CALL SVPW                                                            IFD02590
      CALL INITAL                                                          IFD02600
      CALL MATCON                                                          IFD02610
      CALL SFIELD (FRQ,C0,ZS,N,DZ,U)                                       IFD02620
      CALL WRITE1                                                          IFD02630
      CALL PRINT1                                                          IFD02640
   10 CALL NEWSEG                                                          IFD02650
      CALL NEWMAT                                                          IFD02660
      IF ( NSTEP.EQ.1 ) GO TO 10                                           IFD02670
C                                                                          IFD02680
C     *** THIS LOOP ADVANCES THE SOLUTION ALONG ONE ENTIRE LINEAR          IFD02690
C     *** BOTTOM SEGMENT                                                   IFD02700
          DO 80 ISTEP=2,NSTEP                                              IFD02710
C             *** UPDATE RANGES                                            IFD02720
                  RA1 =  R1 + (ISTEP-1)*DR                                 IFD02730
                  RA2 =  RA1 + DR                                          IFD02740
C             *** IS SEGMENT SLOPING DOWN, LEVEL, UP, MODIFIED DOWN,       IFD02750
C             *** OR MODIFIED UP?                                          IFD02760
                  GO TO (20,30,40,50,60), ISLOPE                           IFD02770
C                 *** BOTTOM SLOPES DOWN                                   IFD02780
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 20                    CALL DOWN                                              IFD02790
                       GO TO 70                                               IFD02800
C                  *** BOTTOM IS LEVEL                                        IFD02810
 30                    CALL LEVEL                                             IFD02820
                       GO TO 70                                               IFD02830
C                  *** BOTTOM SLOPES UP                                       IFD02840
 40                    CALL UP                                                IFD02850
                       GO TO 70                                               IFD02860
C                  *** BOTTOM SLOPES DOWN SLOWLY, BOTTOM MODIFIED             IFD02870
 50                    CALL SSLOPE                                            IFD02880
                       GO TO 70                                               IFD02890
C                  *** BOTTOM SLOPES UP SLOWLY, BOTTOM MODIFIED               IFD02900
 60                    CALL SSLOPE                                            IFD02910
C                                                                             IFD02920
 70             CONTINUE                                                      IFD02930
                CALL ATTENU(U,ATT,IA,NA)                                      IFD02940
                RA2P = RA2+0.5                                                IFD02950
C               *** TIME TO WRITE?                                            IFD02960
                IF (RA2P.GE.XWR) CALL WRITE2                                  IFD02970
C               *** TIME TO PRINT?                                            IFD02980
                IF (RA2P.GE.XPR) CALL PRINT2                                  IFD02990
C               *** TIME TO TERMINATE?                                        IFD03000
                IF (RA2.GE.RMAX) GO TO 90                                     IFD03010
 80         CONTINUE                                                          IFD03020
C                                                                             IFD03030
C       *** GO BACK AND CONTINUE WITH NEXT LINEAR BOTTOM SEGMENT              IFD03040
           GO TO 10                                                           IFD03050
C                                                                             IFD03060
C       *** TIME TO TERMINATE                                                 IFD03070
 90    CONTINUE                                                               IFD03080
C      WRITE(21,100)((DIFD(I,J),J=1,151),I=1,151)                             IFD03090
C00    FORMAT(10F7.2)                                                         IFD03100
       WRITE(27,101)((DIFD(I,J),J=1,121),I=1,121)                             IFD03110
 101   FORMAT(10F7.2)                                                         IFD03120
           CALL END (RA2)                                                     IFD03130
       STOP                                                                   IFD03140
       END                                                                    IFD03150
C                                                                             IFD03160
C                                                                             IFD03170
C                                                                             IFD03180
C                                                                             IFD03190
       SUBROUTINE READ                                                        IFD03200
C                                                                             IFD03210
C          (1)  THIS SUBROUTINE READS ALL INPUT DATA.                         IFD03220
C          (2)  THE DATA IS READ FROM INPUT UNIT NUMBER:  NIU = 51            IFD03230
C          (3)  INPUT FILENAME AND FILETYPE ARE:  IFDIN  DATAIN               IFD03240
C          (4)  DATA IS READ IN FREE FORMAT.                                  IFD03250
C          (5)  DATA IS TRANSFERRED BACK TO MAIN PROGRAM VIA COMMON BLOCK     IFD03260
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C                                                                       IFD03270
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBOT,NM1,    IFD03280
     *       NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                              IFD03290
      COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,     IFD03300
     *       CSVP(101),C2,CWATER(5000),DR,DRIVL,DRMAX,DZ,FRQ,FDR,FDZ,   IFD03310
     *       R1,RA1,RA2,RHO1,RHO2,RMAX,THETA,XKO,XLAMDA,XPR,XX4,XX10,   IFD03320
     *       XX11,XXF,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR            IFD03330
      DATA NIU/51/, NOUT/55/                                            IFD03340
C                                                                       IFD03350
C     *** READ INPUT PARAMETERS                                         IFD03360
      READ(NIU,*,END=100) FRQ, ZS, ZR, C0, N                            IFD03370
      READ(NIU,*,END=100) RMAX, DRLVL, DRMAX, WDR, FDR, FDZ             IFD03380
C                                                                       IFD03390
C     *** READ BOTTOM PROFILE - RANGE, DEPTH                            IFD03400
      DO 10 I=1,101                                                     IFD03410
         READ(NIU,*,END=100) BR(I), BZ(I)                               IFD03420
         NBOT=I                                                         IFD03430
C        *** END OF PROFILE?                                            IFD03440
             IF(BR(I).LT.0.0) GO TO 20                                  IFD03450
C        *** NO                                                         IFD03460
 10   CONTINUE                                                          IFD03470
C                                                                       IFD03480
 20   CONTINUE                                                          IFD03490
C     *** EXTEND LAST DEPTH BEYOND MAX RANGE                            IFD03500
      BR(NBOT) = 1.0E+10                                                IFD03510
      BZ(NBOT) = BZ(NBOT-1)                                             IFD03520
C                                                                       IFD03530
C     *** FIRST LAYER IS WATER. SECOND IS SEDIMENT.                     IFD03540
C     *** READ MAX DEPTH, DENSITY AND ATTENUATION OF FIRST LAYER        IFD03550
      READ(NIU,*,END=100) ZLYR1, RHO1, BETA1                            IFD03560
C                                                                       IFD03570
C     *** READ SOUND SPEED PROFILE IN FIRST LAYER                       IFD03580
      DO 25 I=1,101                                                     IFD03590
         NSVP=I                                                         IFD03600
         READ(NIU,*,END=100) ZSVP(I), CSVP(I)                           IFD03610
C        *** READ ANOTHER PROFILE POINT?                                IFD03620
             IF(ZSVP(I).LT.ZLYR1) GO TO 25                              IFD03630
C        *** NO                                                         IFD03640
C        *** WAS THAT THE LAST PROFILE POINT?                           IFD03650
             IF(ZSVP(I).EQ.ZLYR1) GO TO 30                              IFD03660
C        *** NO, THERE IS ERROR.                                        IFD03670
             GO TO 101                                                  IFD03680
 25   CONTINUE                                                          IFD03690
C                                                                       IFD03700
C     *** DOES THE SOUND SPEED PROFILE START AT THE SURFACE?            IFD03710
 30   IF ( ZSVP(1).NE.0.0 ) GO TO 102                                   IFD03720
C     *** YES                                                           IFD03730
C                                                                       IFD03740
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C      *** READ DEPTH, DENSITY, ATTENUATION AND SPEED IN SECOND LAYER     IFD03750
       READ(NIU,*,END=100) ZLYR2, RHO2, BETA2,C2                         IFD03760
C      *** READ DEPTH OF UPPER EDGE OF ARTIFICIAL ATTENUATING LAYER       IFD03770
       READ(NIU,*,END=100) ZABLYR                                        IFD03780
       RETURN                                                            IFD03790
C                                                                        IFD03800
C      *** ERROR EXITS                                                   IFD03810
  100  WRITE(6,900)                                                      IFD03820
       WRITE(NPOUT,900)                                                  IFD03830
       STOP                                                              IFD03840
  101  WRITE(6,901)                                                      IFD03850
       WRITE(NPOUT,901)                                                  IFD03860
       STOP                                                              IFD03870
  102  WRITE(6,902)                                                      IFD03880
       WRITE(NPOUT,902)                                                  IFD03890
       STOP                                                              IFD03900
C                                                                        IFD03910
  900  FORMAT(//,1X,'ERROR:  EXPECTING MORE INPUT DATA. ',//, 9X,        IFD03920
     *       'EXECUTION TERMINATED.',//)                                 IFD03930
  901  FORMAT(//,' ERROR:  FINAL DEPTH IN SOUND SPEED PROFILE DOES NOT ' IFD03940
     *       ,/,9X,'EQUAL MAXIMUM DEPTH OF WATER COLUMN.',//,9X,         IFD03950
     *       'EXECUTION TERMINATED.',//)                                 IFD03960
  902  FORMAT(//,' ERROR:  FIRST DEPTH IN SOUND SPEED PROFILE'           IFD03970
     *       ,/,9X,'DOES NOT EQUAL ZERO.',//,9X,                         IFD03980
     *       'EXECUTION TERMINATED.',//)                                 IFD03990
C                                                                        IFD04000
       END                                                               IFD04010
C                                                                        IFD04020
CCC                                                                      IFD04030
CCC                                                                      IFD04040
C                                                                        IFD04050
       SUBROUTINE SVP                                                    IFD04060
C                                                                        IFD04070
CCC        (1)  THIS SUBROUTINE CALCULATES THE VERTICAL STEP SIZE:  DZ   IFD04080
CCC        (2)  THIS SUBROUTINE ALSO CALCULATES THE SPEED OF SOUND AT    IFD04090
CCC             EACH OF THE VERTICAL GRID POINTS.                        IFD04100
CCC        (3)  SOUND SPEED VALUES ARE DETERMINED BY LINEAR INTERPOLATION.IFD04110
CCC        (4)  SOUND SPEEDS ARE STORED IN CWATER(I).                    IFD04120
CCC               (A)  THE INDEX I RANGES FROM 1 TO NWMAX.               IFD04130
CCC               (B)  CWATER(1) CORRESPONDS TO THE GRID POINT DZ BELOW  IFD04140
CCC                    THE SURFACE.                                      IFD04150
CCC                                                                      IFD04160
       COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBCT,NM1,    IFD04170
     *       NSTEP,NSTEP1,NSVP,NWMAX,NXIFS                               IFD04180
       COMMON /REAL/ ALPHA,AIT(5000),BETA1,BETA2,BR(101),BZ(101),C0,     IFD04190
     *       CSVP(101),C2,CWATER(5000),DR,DRIVL,DRMAX,DZ,FRQ,FDR,FDZ,    IFD04200
     *       R1,RA1,RA2,RHO1,RHO2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,    IFD04210
     *       XX11,XXF,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZABLYR             IFD04220
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C                                                                       IFD04230
C     ***CALCULATE VERTICAL STEP SIZE                                   IFD04240
      DZ = ZLYR2 / FLOAT(N)                                             IFD04250
C                                                                       IFD04260
C     ***CALCULATE NUMBER OF GRID POINTS IN WATER COLUMN                IFD04270
      NWMAX = INT((ZLYR1/DZ)+0.5)                                       IFD04280
C                                                                       IFD04290
C     ***CALCULATE SOUND SPEED AT ALL GRID POINTS IN WATER COLUMN       IFD04300
      I = 1                                                             IFD04310
      DO 20 I=1,NWMAX                                                   IFD04320
         ZI = I*DZ                                                      IFD04330
         LP1 = L+1                                                      IFD04340
C        ***NEED TO UPDATE PROFILE ENDPOINTS?                           IFD04350
            IF (ZI.LE.ZSVP(IP1)) GO TO 10                               IFD04360
C        ***YES                                                         IFD04370
            I = L+1                                                     IFD04380
            LP1 = I+1                                                   IFD04390
 10      CWATER(I) = CSVP(L) + (CSVP(LP1)-CSVP(L)) * (ZI-ZSVP(L)) /     IFD04400
     *                (ZSVP(IP1)-ZSVP(L))                              IFD04410
 20      CONTINUE                                                       IFD04420
C                                                                       IFD04430
      RETURN                                                            IFD04440
      END                                                               IFD04450
C                                                                       IFD04460
C                                                                       IFD04470
C                                                                       IFD04480
C                                                                       IFD04490
      SUBROUTINE INITAL                                                 IFD04500
C                                                                       IFD04510
C        (1)  THIS SUBROUTINE INITIALIZES CONSTANTS AND VARIABLES.      IFD04520
C        (2)  VALUES ARE TRANSFERRED TO/FROM MAIN PROGRAM VIA COMMON    IFD04530
C             BLOCK.                                                    IFD04540
C                                                                       IFD04550
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBCT,NM1,    IFD04560
     *       NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                              IFD04570
      COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,     IFD04580
     *       CSVP(101),C2,CWATER(5000),DR,DRLVL,DRMAX,DZ,FRQ,PDR,PDZ,   IFD04590
     *       R1,RA1,RA2,RHC1,RHC2,RMAX,THETA,XKO,XLAMDA,XPR,XX4,XX10,   IFD04600
     *       XX11,XWB,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR            IFD04610
      DATA PI/3.141592654/                                              IFD04620
C                                                                       IFD04630
C     *** IF C0 NOT SPECIFIED, SET C0 TO AVERAGE SPEED IN WATER COLUMN  IFD04640
C     *** (USING MAX DEPTH PROFILE)                                     IFD04650
      IF(C0.NE.0.0) GO TO 11                                            IFD04660
      DO 10 I=2,NSVP                                                    IFD04670
         C0=C0+(ZSVP(I)-ZSVP(I-1))*(CSVP(I-1) +                         IFD04680
     *         0.5 *(CSVP(I)-CSVP(I-1)))                                IFD04690
 10      CONTINUE                                                       IFD04700
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            C0 = C0/ZSVE(NSVP)                                                  IFD04710
   11       CONTINUE                                                            IFD04720
C                                                                               IFD04730
C       *** INITIALIZE RANGE                                                    IFD04740
            RA1 = 0.0                                                           IFD04750
C                                                                               IFD04760
C       *** INITIALIZE POINTER THAT POINTS TO BOTTOM PROFILE POINT              IFD04770
            IEOT1 = 0                                                           IFD04780
C                                                                               IFD04790
C       *** COMPUTE REFERENCE WAVE NUMBER                                       IFD04800
            XK0 = 2.0*PI*FRQ/C0                                                 IFD04810
C                                                                               IFD04820
C       *** COMPUTE REFERENCE WAVELENGTH                                        IFD04830
            XLAMDA = C0/FRQ                                                     IFD04840
C                                                                               IFD04850
C       *** IF DRLVL=0 SET DRLVL EQUAL TO 1/2 REFERENCE WAVELENGTH              IFD04860
            IF ( DRLVL.EQ.0.0 )  DRLVL = 0.5 * XLAMDA                           IFD04870
C                                                                               IFD04880
C       *** IF DRMAX=0 SET DRMAX EQUAL TO REFERENCE WAVELENGTH                  IFD04890
            IF ( DRMAX.EQ.0.0 ) DRMAX = XLAMDA                                  IFD04900
C                                                                               IFD04910
C       *** IF DRLVL GREATER THAN DRMAX SET DRLVL EQUAL TO DRMAX                IFD04920
            IF (DRLVL.GT.DRMAX) DRLVL = DRMAX                                   IFD04930
C                                                                               IFD04940
C       *** COMPUTE ATTENUATION - SACLANT MEMO SM-121 (JENSEN + FERLA)          IFD04950
C       *** MODIFIED AS FOLLOWS:                                                IFD04960
C       *** IF INPUTTED BETA IS IT 0.0, ALPHA IS COMPUTED IN DB/METER           IFD04970
C       *** AND USED FOR BETA                                                   IFD04980
            ALPHA=FRQ*FRQ*(.007+(.155*1.7)/(1.7*1.7+FRQ*FRQ*.000001))          IFD04990
     *           *1.0E-09                                                       IFD05000
C                                                                               IFD05010
C       *** INITIALIZE POINTER THAT POINTS TO INTERFACE GRID POINT              IFD05020
            IFACE = INT ( BZ(1)/DZ + 0.5 )                                      IFD05030
C                                                                               IFD05040
            RETURN                                                              IFD05050
            END                                                                 IFD05060
C                                                                               IFD05070
C                                                                               IFD05080
C                                                                               IFD05090
C                                                                               IFD05100
            SUBROUTINE MATCON                                                   IFD05110
C                                                                               IFD05120
C       THIS SUBROUTINE CALCULATES VARIOUS VARIABLES NEEDED TO COMPUTE          IFD05130
C       TRIDIAGINAL MATRIX ELEMENTS.  VARIABLES BEGINNING WITH XX HAVE          IFD05140
C       NO SPECIAL PHYSICAL SIGNIFICANCE BUT THEY CONTRIBUTE TO                 IFD05150
C       COMPUTATIONAL EFFICIENCY.                                               IFD05160
C                                                                               IFD05170
            COMPLEX XN1                                                         IFD05180
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      COMPLEX A,A2,C,CR,CTWC,EYE,                                       IFD05190
     *        XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                           IFD05200
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,                 IFD05210
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,             IFD05220
     *        U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                 IFD05230
      COMMON /INT/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBCI,NM1,   IFD05240
     *        NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                              IFD05250
      COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,     IFD05260
     *        CSVP(101),C2,CWATER(5000),DR,DRLVL,DRMAX,DZ,FRQ,FDR,FDZ,   IFD05270
     *        R1,RA1,RA2,RHO1,RHO2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,   IFD05280
     *        XX11,XWR,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR             IFD05290
      COMMON /CPLX/  A(5000),A2,C(5000,4),CR(5000),CTWC(5000),          IFD05300
     *        EYE,XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                       IFD05310
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),           IFD05320
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,       IFD05330
     *        U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                           IFD05340
C                                                                       IFD05350
      EYE = CMPLX(0.0,1.0)                                              IFD05360
C                                                                       IFD05370
      XX1 = CMPLX ( 0.0 , +0.25/(DZ*DZ*XK0) )                           IFD05380
      XX2 = 2.0 * XX1                                                   IFD05390
C     *** COMPUTE COEFFICIENT A IN SEDIMENT LAYER                       IFD05400
C        *** FIRST CALCULATE REAL INDEX OF REFRACTION                   IFD05410
            XN = C0/C2                                                  IFD05420
C        *** THEN CALCULATE COMPLEX INDEX OF REFRACTION SQUARED         IFD05430
C        ***     (SEE PAGE 2-11 IN TR 6659)                             IFD05440
            XN1 = CMPLX ( XN*XN , XN*XN*BETA2/27.287527 )               IFD05450
C        *** CALCULATE A2                                               IFD05460
            A2 = 0.5 * EYE * XK0 * (XN1-1.0)                            IFD05470
      XX3 = 0.5*A2 - XX2                                                IFD05480
      XX4 = 1.0 + RHO1/RHO2                                             IFD05490
      XX5 = XX2*(1.0/XX4 - 1.0) + A2/(2.0*(RHO2/RHO1 + 1.0))            IFD05500
      XX6 = XX2/XX4                                                     IFD05510
      XX7 = RHO1/RHO2 * XX6                                             IFD05520
      XX8 = CMPLX ( 0.0 , -DZ*XK0 )                                     IFD05530
      XX9 = 1.0 / XX8                                                   IFD05540
      XX10 = RHO1 + RHO2                                                IFD05550
      XX11 = RHO1 - RHO2                                                IFD05560
      XX12 = 4.0 * XX1                                                  IFD05570
C                                                                       IFD05580
C        *** THIS SECTION PERTAINS TO POINTS IN WATER COLUMN             IFD05590
            DO 10 I=1,NWMAX                                             IFD05600
C              *** CALCULATE REAL INDEX OF REFRACTION IN WATER          IFD05610
                  XN = C0/CWATER(I)                                     IFD05620
C              *** CALCULATE ATTENUATION AS PER COMMENTS IN SUBROUTINE   IFD05630
C              *** INITAL                                               IFD05640
                  IF (BETA1.LT.0.0) BETA1 = ALPHA*CWATER(I)/FRQ         IFD05650
C              *** CALCULATE COMPLEX INDEX OF REFRACTION SQUARED        IFD05660
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C               ***    (SEE PAGE 2-11 IN TR 6659)                                IFD05670
                    XN1 = CMPLX ( XN*XN , XN*XN*BETA1/27.287527 )                 IFD05680
C               *** CALCULATE COEFFICIENT A(I)                                    IFD05690
                    A(I) = 0.5 * EYE * XK0 * (XN1- 1.0)                           IFD05700
C               *** CALCULATE XX1M                                                IFD05710
                    XX1M(I) = 0.5 * A(I)   -   XX2                                IFD05720
 10         CONTINUE                                                              IFD05730
      RETURN                                                                      IFD05740
      END                                                                         IFD05750
C                                                                                 IFD05760
C                                                                                 IFD05770
C                                                                                 IFD05780
C                                                                                 IFD05790
      SUBROUTINE SFIELD(FRQ,C0,ZS,N,DZ,U)                                         IFD05800
C                                                                                 IFD05810
C     *** THIS SUBROUTINE IS IDENTICAL TO SUBROUTINE SFIELD AS PER                IFD05820
C     *** NUSC TECHNICAL REPORT 6659.                                             IFD05830
C                                                                                 IFD05840
C     ************************************************************              IFD05850
C     *** GAUSSIAN STARTING FIELD - SEE NORDA TECH NOTE 12 BY H.K.BROCK          IFD05860
C     ************************************************************              IFD05870
C                                                                                 IFD05880
C     *** CALLING ROUTINE SUPPLIES:                                               IFD05890
C         FRQ - FREQUENCY IN HZ                                                   IFD05900
C         C0  - REFERENCE SOUND SPEED - METERS/SEC                                IFD05910
C         ZS  - DEPTH OF SOURCE IN METERS.                                        IFD05920
C         N   - NUMBER OF POINTS IN ARRAY U                                       IFD05930
C         DZ  - DEPTH INCREMENT - METERS                                          IFD05940
C     *** SFIELD SUBROUTINE SUPPLIES:                                             IFD05950
C         U   - COMPLEX STARTING FIELD                                            IFD05960
C     ************************************************************              IFD05970
C                                                                                 IFD05980
      COMPLEX U(1)                                                                IFD05990
      DATA PI/3.1415926535/                                                       IFD06000
C                                                                                 IFD06010
C     THE FIELD IS DEFINED AS A GAUSSIAN BEAM AT RANGE = 0.                       IFD06020
C     LOCAL VARIABLES - GA  GAUSSIAN AMPLITUDE                                    IFD06030
      XK0=2.0*PI*FRQ/C0                                                           IFD06040
      GW=2.0/XK0                                                                  IFD06050
      GA=SQRT(GW)/GW                                                              IFD06060
      DO 10 I=1,N                                                                 IFD06070
      ZM=I*DZ                                                                     IFD06080
      PR=GAUSS(GA,ZM,ZS,GW)-GAUSS(GA,-ZM,ZS,GW)                                   IFD06090
      U(I)=CMPLX(PR,0.0)                                                          IFD06100
 10   CONTINUE                                                                    IFD06110
      RETURN                                                                      IFD06120
      END                                                                         IFD06130
      FUNCTION GAUSS(GA,Z,GD,GW)                                                  IFD06140
```

```
C      INPUT  - GA  GAUSSIAN AMPLITUDE                                  IFD06150
C      OUTPUT - GAUSS = GA * EXP(-((Z - GD) / GW)**2)                   IFD06160
C      TEMPORARY VARIABLE - V                                           IFD06170
       V=(Z-GD)/GW                                                      IFD06180
       V=-(V*V)                                                         IFD06190
       GAUSS=GA*EXP(V)                                                  IFD06200
       RETURN                                                           IFD06210
       END                                                              IFD06220
C                                                                       IFD06230
CC                                                                      IFD06240
CCC                                                                     IFD06250
C                                                                       IFD06260
       SUBROUTINE WRITE1                                                IFD06270
C                                                                       IFD06280
CC        (1)  THIS SUBROUTINE OUTPUTS UNFORMATTED DATA TO A FILE       IFD06290
CC             THAT IS USED BY THE PLOTTING ROUTINE.                    IFD06300
CC        (2)  THE FILE CORRESPONDS TO UNIT FILE NUMBER:  NOU = 52       IFD06310
CC        (3)  THE FILENAME AND FILETYPE FOR THIS FILE ARE:              IFD06320
CC                  IFLOUT   PLOTTER                                    IFD06330
C                                                                       IFD06340
       COMPLEX A,A2,C,CR,CTWC,EYE,                                      IFD06350
      *        XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                         IFD06360
      *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,               IFD06370
      *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,           IFD06380
      *        U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                               IFD06390
       COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBOT,NM1,   IFD06400
      *        NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                            IFD06410
       COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,    IFD06420
      *        CSVP(101),C2,CWATER(5000),DR,DRLVL,DRMAX,DZ,FRQ,PDR,PDZ, IFD06430
      *        R1,RA1,RA2,RHO1,RHO2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,  IFD06440
      *        XX11,XWR,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR           IFD06450
       COMMON /CPIX/  A(5000),A2,C(5000,4),CR(5000),CTWC(5000),         IFD06460
      *        EYE,XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                     IFD06470
      *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),         IFD06480
      *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,     IFD06490
      *        U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                         IFD06500
       DATA NOU/52/                                                     IFD06510
C                                                                       IFD06520
C      *** WRITE MAXIMUM RANGE                                          IFD06530
           WRITE(NOU,*) RMAX                                            IFD06540
C                                                                       IFD06550
C      *** INITIALIZE RANGE VARIABLE AT WHICH SOLUTION IS TO BE RECORDED IFD06560
           XWR = RA1+WIR                                                IFD06570
C                                                                       IFD06580
C      *** COMPUTE RECEIVER DEPTH TO NEAREST DZ                         IFD06590
           IF ( ZR.LT.DZ ) ZR = DZ                                      IFD06600
           IWZ = ZR/DZ + 0.5                                            IFD06610
           ZR = IWZ*DZ                                                  IFD06620
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C                                                                       IFD06630
C     *** WRITE STARTING VALUE                                          IFD06640
      WRITE(NOU,*)  RA1, ZR, U(IWZ)                                     IFD06650
C                                                                       IFD06660
      RETURN                                                            IFD06670
      END                                                               IFD06680
C                                                                       IFD06690
CC                                                                      IFD06700
CC                                                                      IFD06710
C                                                                       IFD06720
      SUBROUTINE PRINT1                                                 IFD06730
C                                                                       IFD06740
CC       (1)  THIS SUBROUTINE OUTPUTS FORMATTED DATA TO A FILE          IFD06750
CC            WHICH IS READY TO BE SENT TO THE PRINTER.                 IFD06760
CC       (2)  THE FILE CORRESPONDS TO UNIT FILE NUMBER:  NPOUT = 55     IFD06770
CC       (3)  THE FILENAME AND FILETYPE FOR THIS FILE ARE:              IFD06780
CC               IFDOUT    PRINTER                                     IFD06790
C                                                                       IFD06800
      DIMENSION ID(17)                                                  IFD06810
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBCT,NM1,    IFD06820
     *          NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                           IFD06830
      COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,     IFD06840
     *          CSVP(101),C2,CWATER(5000),DR,DRLVL,DRMAX,DZ,FRQ,EDR,EDZ,IFD06850
     *          R1,RA1,RA2,RHO1,RHO2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,IFD06860
     *          XX11,XWR,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZABLYR         IFD06870
      DATA NPOUT/55/                                                    IFD06880
C                                                                       IFD06890
C     *** PROMPT USER FOR RUN IDENTIFICATION                            IFD06900
      WRITE(6,890)                                                      IFD06910
C     *** READ USER RESPONSE                                            IFD06920
      READ(5,891) ( ID(I), I=1,16 )                                     IFD06930
C                                                                       IFD06940
C     *** PRINT SELECTED PARAMETERS OF INTEREST                         IFD06950
      WRITE(NPOUT,900)  (ID(I), I=1,16),  FRQ, ZS, ZR, DZ, C0, XK0,     IFD06960
     *                  XLAMDA, RMAX, DRLVL, DRMAX, WDR, ZABLYR, N      IFD06970
C                                                                       IFD06980
C     *** PRINT SOUND SPEED PROFILE IN WATER                            IFD06990
      WRITE(NPOUT,904)                                                  IFD07000
      DO 5 I=1,NSVP                                                     IFD07010
         WRITE(NPOUT,905) ZSVP(I), CSVP(I)                              IFD07020
5     CONTINUE                                                          IFD07030
C                                                                       IFD07040
C     *** PRINT MORE SELECTED PARAMETERS OF INTEREST                    IFD07050
      WRITE(NPOUT,901)  ZLYR1, RHO1, BETA1, ZLYR2, RHO2, BETA2, C2      IFD07060
C                                                                       IFD07070
C     *** PRINT BOTTOM PROFILE                                          IFD07080
      WRITE(NPOUT,902)                                                  IFD07090
      NBOTM1 = NBCT-1                                                   IFD07100
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            DO 10 I=1,NEOTM1                                                    IFD07110
               WRITE(NPCUT,903) ER(I), BZ(I)                                    IFD07120
 10         CONTINUE                                                            IFD07130
C                                                                               IFD07140
C      *** COMPUTE DEPTH PRINT INCREMENT TO NEAREST DZ                          IFD07150
            IPZ = INT ( PDZ/DZ+0.5 )                                            IFD07160
            IF ( IPZ.EQ.0 ) IPZ = 1                                             IFD07170
C                                                                               IFD07180
C      *** INITIALIZE RANGE VARIABLE AT WHICH SOLUTION IS TO BE PRINTED         IFD07190
            XPR = RA1+PIR                                                       IFD07200
C                                                                               IFD07210
 890    FORMAT( /,1X,'ENTER RUN IDENTIFICATION:')                               IFD07220
 891    FORMAT(16A4)                                                            IFD07230
 900    FORMAT(///,1X,'IFD PRINTED OUTPUT',//,1X,'RUN I.D. :  ',               IFD07240
     *       16A4,///,7X,'GAUSSIAN STARTING ',                                  IFD07250
     *       'FIELD',//,7X,'(FOR FURTHER INFORMATION ON VARIABLES',             IFD07260
     *       ' SEE MAIN IFD PROGRAM LISTING)',//,                               IFD07270
     *  7X,'FREQUENCY                              FRQ    = ',F9.2,' HZ',//    IFD07280
     *  7X,'SOURCE DEPTH                           ZS     = ',F9.3,' M',//     IFD07290
     *  7X,'RECEIVER DEPTH                         ZR     = ',F9.3,' M',//     IFD07300
     *  7X,'DEPTH INCREMENT                        DZ     = ',F9.3,' M',//     IFD07310
     *  7X,'REF SOUND SPEED                        C0     = ',F9.3,' M/S',//   IFD07320
     *  7X,'REF WAVE NUMBER                        XK0    = ',F9.3,' 1/M',//   IFD07330
     *  7X,'REF WAVELENGTH                         XLAMDA = ',F9.3,' M',//     IFD07340
     *  7X,'MAX RANGE OF SOLUTION                  RMAX   = ',F9.3,' M',//     IFD07350
     *  7X,'RANGE STEP ON HORIZONTAL SECTION       DRLVL  = ',F9.3,' M',//     IFD07360
     *  7X,'MAXIMUM RANGE STEP                     DRMAX  = ',F9.3,' M',//     IFD07370
     *  7X,'RECORDED RANGE STEP                    WDR    = ',F9.3,' M',//     IFD07380
     *  7X,'DEPTH OF UPPER EDGE ART ATTENU LYR     ZABLYR = ',F9.3,' M',//     IFD07390
     *  7X,'#VERTICAL POINTS IN GRID                N          = ',I6,//)      IFD07400
 901    FORMAT(///' LAYER       MAX DEPTH(M)       DENSITY(G/CM**3)   ',       IFD07410
     *       'ATT(DB/WL)      SOUND SPEED',//                                   IFD07420
     *       ' WATER    ',F13.1,5X,F13.2,5X,F13.6,5X,'SEE PROFILE ABOVE'       IFD07430
     *       ,///,' SEDIMENT',F13.1,5X,F13.2,5X,F13.6,4X,F13.2,///)             IFD07440
 902    FORMAT(///,' BOTTOM PROFILE:',//,25X,'RANGE',13X,'DEPTH',//)            IFD07450
 903    FORMAT(20X,F10.3,' M',5X,F11.3,' M',//)                                 IFD07460
 904    FORMAT(///,' SOUND SPEED PROFILE IN WATER:',//,20X,'DEPTH',             IFD07470
     *       10X,'SOUND SPEED',//)                                              IFD07480
 905    FORMAT(14X,F10.3,' M',6X,F10.2,' M/S',/)                                IFD07490
C                                                                               IFD07500
       RETURN                                                                   IFD07510
       END                                                                      IFD07520
C                                                                               IFD07530
CC                                                                              IFD07540
C                                                                               IFD07550
C                                                                               IFD07560
       SUBROUTINE NEWSEG                                                        IFD07570
C                                                                               IFD07580
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C     THIS SUBROUTINE IS CALLED AT THE START OF EACH NEW BOTTOM          IFD07590
C     SEGMENT.  THE SUBROUTINE DOES THE FOLLOWING TASKS FOR EACH         IFD07600
C     BOTTOM SEGMENT:                                                    IFD07610
C        (1)  UPDATES BOTTOM PROFILE POINTERS:  IBOT1 & IEOT2            IFD07620
C        (2)  COMPUTES SLOPE:  THETA                                     IFD07630
C        (3)  COMPUTES NUMBER OF RANGE STEPS IN SEGMENT:  NSTEP          IFD07640
C        (4)  COMPUTES RANGE STEP:  DR                                   IFD07650
C        (5)  SETS SLOPE FLAG :  ISLOPE                                  IFD07660
C               (A)  ISLOPE = 1   -   BOTTOM SLOPES DOWN                 IFD07670
C               (B)  ISLOPE = 2   -   BOTTOM LEVEL                       IFD07680
C               (C)  ISLOPE = 3   -   BOTTOM SLOPES UP                   IFD07690
C               (D)  ISLOPE = 4   -   BOTTOM SLOPES DOWN, MODIFY BOTTOM  IFD07700
C               (E)  ISLOPE = 5   -   BOTTOM SLOPES UP, MODIFY BOTTOM    IFD07710
C        (6)  INIALIZES RANGES:  RA1 & RA2                               IFD07720
C        (7)  CHECKS THAT RANGE STEP IS LESS THAN DRMAX                  IFD07730
C        (8)  ISSUES ERROR OR WARNING MESSAGES AS APPROPRIATE            IFD07740
C                                                                        IFD07750
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBCT,NM1,     IFD07760
     *      NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                                IFD07770
      COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,      IFD07780
     *      CSVP(101),C2,CWATER(5000),DR,DRLVL,DRMAX,DZ,FRQ,PDR,PDZ,     IFD07790
     *      R1,RA1,RA2,RHO1,RHO2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,     IFD07800
     *      XX11,XWP,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR              IFD07810
      DATA NPOUT/55/                                                     IFD07820
C                                                                        IFD07830
C     *** UPDATE BOTTOM PROFILE POINTER                                  IFD07840
      IBOT1 = IBOT1 + 1                                                  IFD07850
      IEOT2 = IBOT1 + 1                                                  IFD07860
C     *** GET STARTING AND ENDING RANGES AND DEPTHS FOR THIS SEGMENT     IFD07870
      R1 = BR(IBOT1)                                                     IFD07880
      Z1 = BZ(IBOT1)                                                     IFD07890
      R2 = BR(IBOT2)                                                     IFD07900
      Z2 = BZ(IBOT2)                                                     IFD07910
C        *** ERROR CHECK                                                 IFD07920
         IF (R2.LE.R1) GO TO 100                                         IFD07930
C        *** PUT Z1 AND Z2 ON NEAREST GRID POINTS                        IFD07940
         ITEMP = INT ( Z1/DZ + 0.5 )                                     IFD07950
         Z1 = DZ * FLOAT(ITEMP)                                          IFD07960
         ITEMP = INT ( Z2/DZ + 0.5 )                                     IFD07970
         Z2 = DZ * FLOAT(ITEMP)                                          IFD07980
C     *** COMPUTE SLOPE                                                  IFD07990
      THETA = ATAN2 (Z2-Z1,R2-R1)                                        IFD08000
C     *** DOES BOTTOM SLOPE DOWN, LEVEL OR UP?                           IFD08010
      IF (THETA.GT.0.0)  GO TO 10                                        IFD08020
      IF (THETA.LT.0.0)  GO TO 20                                        IFD08030
C                                                                        IFD08040
C        *** BOTTOM IS LEVEL                                             IFD08050
C           *** DETERMINE NUMBER OF RANGE STEPS FOR SEGMENT              IFD08060
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                NSTEP = INT ( (R2-R1)/DRLVL + 0.99999 )                 IFD08070
C             *** DETERMINE RANGE STEP                                  IFD08080
                DR = (R2-R1) / FLOAT(NSTEP)                             IFD08090
C             *** SET ISLOPE                                            IFD08100
                ISLOPE = 2                                              IFD08110
              GO TO 80                                                  IFD08120
C                                                                       IFD08130
C           *** BOTTOM SLOPES DOWN                                      IFD08140
C              *** DETERMINE NUMBER OF RANGE STEPS                      IFD08150
 10                NSTEP = INT ( (Z2-Z1+0.05)/DZ )                     IFD08160
C              *** DETERMINE RANGE STEP                                 IFD08170
                  DR = (R2-R1)/FLOAT(NSTEP)                             IFD08180
C              *** SET ISLOPE                                           IFD08190
                  ISLOPE = 1                                            IFD08200
               GO TO 30                                                 IFD08210
C                                                                       IFD08220
C           *** BOTTOM SLOPES UP                                        IFD08230
C              *** DETERMINE NUMBER OF RANGE STEPS                      IFD08240
 20                NSTEP = INT ( (Z1-Z2+0.05)/DZ )                     IFD08250
C              *** DETERMINE RANGE STEP                                 IFD08260
                  DR = (R2-R1)/FLOAT(NSTEP)                             IFD08270
C              *** SET ISLOPE                                           IFD08280
                  ISLOPE = 3                                            IFD08290
C                                                                       IFD08300
 30    CONTINUE                                                         IFD08310
C      *** IS RANGE STEP TOO LARGE?                                     IFD08320
          IF ( DR.LE.DRMAX ) GO TO 80                                   IFD08330
C      *** YES, BOTTOM MUST BE MODIFIED                                 IFD08340
C          *** SET ISLOPE                                               IFD08350
               ISLOPE = 4                                               IFD08360
               IF ( THETA.LT.0.0 ) ISLOPE = 5                           IFD08370
C          *** DETERMINE NUMBER OF RANGE STEPS REQUIRED TO MOVE UP      IFD08380
C          *** OR DOWN ONE GRID POINT                                   IFD08390
               NSTEP1 = INT ( DR/DRMAX + 0.99999 )                      IFD08400
C          *** DETERMINE RANGE STEP                                     IFD08410
               DR = DR / FLOAT(NSTEP1)                                  IFD08420
C          *** REDETERMINE NUMBER OF RANGE STEPS                        IFD08430
               NSTEP = NSTEP * NSTEP1                                   IFD08440
C          *** COMPUTE SLOPE OF SLOPING SECTION                         IFD08450
               THETA = ATAN2(DZ,DR)                                     IFD08460
C          *** COMPUTE LOCATION OF NEXT LEVEL SECTION FOLLOWING A       IFD08470
C          *** SLOPING SECTION                                          IFD08480
               NXTFS = NSTEP1/2 + 2                                     IFD08490
C          *** INDICATE TO USER THAT BOTTOM HAS BEEN MODIFIED           IFD08500
               TEMP = 0.5 * DZ                                          IFD08510
               WRITE(6,903) R1,R2,TEMP                                  IFD08520
               WRITE(NEOUT,903) R1,R2,TEMP                              IFD08530
C                                                                       IFD08540
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 80   CONTINUE                                                          IFD08550
C     *** INITIALIZE RA1 & RA2                                          IFD08560
      RA1 = R1                                                          IFD08570
      RA2 = RA1+DR                                                      IFD08580
C                                                                       IFD08590
C     *** INDICATE TO USER HOW FAR SOLUTION FIELD HAS PROGRESSED        IFD08600
      WRITE(6,902) R1                                                   IFD08610
C                                                                       IFD08620
C     *** IF RANGE STEP GREATER THAN 1 (?) WAVELENGTH WRITE WARNING     IFD08630
      IF ( DR.LE.XLAMDA ) GO TO 90                                      IFD08640
         WRITE(6,901) R1, R2, DR, XLAMDA                                IFD08650
         WRITE(NPOUT,901) R1, R2, DR, XLAMDA                            IFD08660
C                                                                       IFD08670
 90   RETURN                                                            IFD08680
C                                                                       IFD08690
C     *** ERROR EXIT                                                    IFD08700
 100      WRITE(6,900) IBOT2, IBOT1                                     IFD08710
          WRITE(NPOUT,900) IBOT2, IBOT1                                 IFD08720
C                                                                       IFD08730
          STOP                                                          IFD08740
C                                                                       IFD08750
 900  FORMAT(//,1X,'ERROR:  THE RANGE AT BOTTOM PROFILE POINT NUMBER ',  IFD08760
     *       I2,' IS LESS'/,9X,'THAN THE RANGE AT BOTTOM PROFILE POINT'  IFD08770
     *       ,' NUMBER ',I2,'.',//,1X,'EXECUTION TERMINATED.'///)       IFD08780
 901  FORMAT(/,                                                          IFD08790
     * ' WARNING:  THE HORIZONTAL RANGE STEP BETWEEN RANGE R  =',F8.1,/  IFD08800
     * '             AND RANGE R =',F8.1,' (METERS) IS',F5.1,' METERS.',//,IFD08810
     * '             THE REFERENCE WAVELENGTH IS',F5.1,' METERS.')      IFD08820
 902  FORMAT(/,' THE PROGRAM HAS REACHED RANGE R =',F8.1,' METERS.')     IFD08830
 903  FORMAT(/,' NOTE:  THE BOTTOM BETWEEN RANGE',F8.1,' AND RANGE',     IFD08840
     *       F8.1,//,8X,'HAS BEEN MODIFIED BECAUSE OF ITS VERY SMALL',  IFD08850
     *       ' SLOPE.',//,8X,'THE DIFFERENCE BETWEEN THE MODIFIED ',    IFD08860
     *       'BOTTOM AND YOUR',//,8X,'INPUT BOTTOM IS NEVER GREATER ',  IFD08870
     *       'THAN',F5.2,' METERS.'/)                                   IFD08880
C                                                                       IFD08890
      END                                                               IFD08900
C                                                                       IFD08910
C                                                                       IFD08920
C                                                                       IFD08930
C                                                                       IFD08940
      SUBROUTINE NEWMAT                                                 IFD08950
C                                                                       IFD08960
C                                                                       IFD08970
C     THIS SUBROUTINE IS CALLED AT THE START OF EACH NEW BOTTOM         IFD08980
C     SEGMENT.  THE SUBROUTINE DOES THE FOLLOWING TASKS:                IFD08990
C        (1)  COMPUTES TRIDIAGONAL MATRIX ELEMENTS FOR MATRIX Y         IFD09000
C             (A)  MATRIX Y IS AT RANGE WHERE FIELD IS KNOWN: RANGE=RA1 IFD09010
C             (B)  Y MATRIX ON RHS OF EQUATION                          IFD09020
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C        (2)  USES Y MATRIX ELEMENTS AND KNOWN FIELD AT RANGE RA1 TO      IFD09030
C             COMPUTE RHS COLUMN VECTOR C(I,4).   (SEE IRIDG AND TEXT)    IFD09040
C        (3)  COMPUTES TRIDIAGONAL MATRIX ELEMENTS FOR MATRIX X           IFD09050
C             (A)  X MATRIX ON LHS OF EQUATION                            IFD09060
C             (B)  X MATRIX VALUES STORED IN C(I,1), C(I,2) AND C(I,3)    IFD09070
C                  (SEE IRIDG AND TEXT REFERENCED IN IRIDG)               IFD09080
C             (C)  X MATRIX AT RANGE:  RA2 = RA1 + DR                     IFD09090
C                                                                         IFD09100
C     TRIDIAGONAL MATRIX ELEMENTS ARE REPRESENTED BY VARIABLES            IFD09110
C     BEGINNING WITH EITHER X OR Y.  FOR VARIABLES BEGINNING WITH X OR    IFD09120
C     Y, THE LETTERS IN THE VARIABLE NAME HAVE THE FOLLOWING              IFD09130
C     SIGNIFICANCE:                                                       IFD09140
C                   X  -  ELEMENT IN X MATRIX                             IFD09150
C                   Y  -  ELEMENT IN Y MATRIX                             IFD09160
C                   M  -  ELEMENT ON MAIN DIAGONAL                        IFD09170
C                   L  -  ELEMENT TO LEFT OF MAIN DIAGONAL                IFD09180
C                   R  -  ELEMENT TO RIGHT OF MAIN DIAGONAL               IFD09190
C                   W  -  ELEMENT IN ROW IN WATER                         IFD09200
C                   I  -  ELEMENT IN ROW AT INTERFACE                     IFD09210
C                   S  -  ELEMENT IN ROW IN SEDIMENT                      IFD09220
C                   V  -  INTERFACE ELEMENT ON LEVEL INTERFACE            IFD09230
C                   Z  -  INTERFACE ELEMENT ON SLOPING INTERFACE          IFD09240
C                                                                         IFD09250
      COMPLEX DELTA,DELIN,BETA1,GAMMA1,BETA2,GAMMA2,ZZ1,ZZ2,ZZ3,ZZ4       IFD09260
      COMPLEX A,A2,C,CR,CIWC,EYE,                                         IFD09270
     *        XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                            IFD09280
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,                  IFD09290
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,              IFD09300
     *        U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                  IFD09310
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBC1,NM1,      IFD09320
     *        NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                               IFD09330
      COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,       IFD09340
     *        CSVP(101),C2,CWATER(5000),DR,DRLVL,DRMAX,DZ,FRQ,PDR,PDZ,    IFD09350
     *        R1,RA1,RA2,RHO1,RHO2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,     IFD09360
     *        XX11,XXF,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR              IFD09370
      COMMON /CPLX/  A(5000),A2,C(5000,4),CR(5000),CIWC(5000),            IFD09380
     *        EYE,XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                        IFD09390
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),            IFD09400
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,        IFD09410
     *        U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                            IFD09420
C                                                                         IFD09430
C     *** COMPUTE MAIN DIAGONAL ELEMENT, Y MATRIX, IN SEDIMENT            IFD09440
      YMS = 1.0 + DR*XX3                                                  IFD09450
C     *** COMPUTE OFF-DIAGONAL ELEMENTS, Y MATRIX, IN WATER & SEDIMENT    IFD09460
      YIRWS = DR*XX1                                                      IFD09470
C     *** COMPUTE MAIN DIAGONAL ELEMENT, X MATRIX, IN SEDIMENT            IFD09480
      XMS = 2.0 - YMS                                                     IFD09490
C     *** COMPUTE OFF-DIAGONAL ELEMENTS, X MATRIX, IN WATER & SEDIMENT    IFD09500
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            XIRWS = -YIRWS                                                    IFD09510
C     ***   COMPUTE FIRST ELEMENT IN RHS COLUMN VECTOR                        IFD09520
            YMW(1) = 1.0 + DR*XX1M(1)                                         IFD09530
            C(1,4) = U(1)*YMW(1) + U(2)*YLRWS                                 IFD09540
C     ***   COMPUTE TWO ELEMENTS IN FIRST ROW ON LHS                          IFD09550
            C(1,2) = 2.0 - YMW(1)                                             IFD09560
            C(1,3) = XIRWS                                                    IFD09570
C     ***   COMPUTE REMAINING ELEMENTS ON BOTH RHS & LHS FOR ROWS IN WATER    IFD09580
            IFACEM = IFACE - 1                                                IFD09590
            DO 10 I=2,IFACEM                                                  IFD09600
C              *** FIRST WORK WITH RHS                                        IFD09610
                  YMW(I) = 1.0 + DR*XX1M(I)                                   IFD09620
                  C(I,4) = U(I)*YMW(I) + (U(I-1)+U(I+1))*YIRWS                IFD09630
C              *** WORK WITH LHS                                              IFD09640
                  C(I,1) = XIRWS                                              IFD09650
                  C(I,2) = 2.0 - YMW(I)                                       IFD09660
                  C(I,3) = XIRWS                                              IFD09670
 10         CONTINUE                                                          IFD09680
C     ***   COMPUTE LHS & RHS ELEMENTS IN SEDIMENT                            IFD09690
            IFACEP = IFACE + 1                                                IFD09700
            NM1 = N - 1                                                       IFD09710
            DO 20 I=IFACEP,NM1                                                IFD09720
C              *** RHS                                                        IFD09730
                  C(I,4) = U(I)*YMS + (U(I-1)+U(I+1))*YLRWS                   IFD09740
C              *** LHS                                                        IFD09750
                  C(I,1) = XIRWS                                              IFD09760
                  C(I,2) = XMS                                                IFD09770
                  C(I,3) = XIRWS                                              IFD09780
 20         CONTINUE                                                          IFD09790
C                                                                             IFD09800
C     ***   IF ENTIRE SEGMENT LEVEL GO TO 50                                  IFD09810
            IF ( ISLOPE.EQ.2 ) GO TO 50                                       IFD09820
C                                                                             IFD09830
C     ***   INTERFACE SLOPES EITHER UP OR DOWN                                IFD09840
C     ***   CALCULATE CONSTANTS FOR COMPUTING MATRIX ELEMENTS                 IFD09850
            THETA = ABS (THETA)                                               IFD09860
            SINE = SIN (THETA)                                                IFD09870
            COSE = COS (THETA)                                                IFD09880
            DELTA = XX10 + XX11*(XX8+XX9)*SINE*COSE                           IFD09890
            DELIN = 1.0 / DELTA                                               IFD09900
            BETA1 = DELIN * XX12 * RHO1                                       IFD09910
            GAMMA1 = DELIN * (XX12*(RHO2*COSE*COSE+RHO1*SINE*SINE) +          IFD09920
     *                 XX11*SINE*COSE/DZ)                                     IFD09930
            BETA2 = DELIN  * (XX12*(RHO1*COSE*COSE+RHO2*SINE*SINE) +          IFD09940
     *                 XX11*SINE*COSE/DZ)                                     IFD09950
            GAMMA2 = DELIN * XX12 * RHO2                                      IFD09960
            ZZ1 = DELIN * (RHO1*SINE*SINE + RHO2*COSE*COSE +                  IFD09970
     *             XX8*SINE*COSE*XX11)                                        IFD09980
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            ZZ2 = DELIN * (RHO1*A2 - (COSE-XX8*SINE)*XX9*XX11*EYE*XKO*      IFD09990
           *     SINE)                                                      IFD10000
            ZZ3 = DELIN * RHO2                                             IFD10010
            ZZ4 = DELIN * (  A2 * ( RHO1*COSE*CCSE + RHO2*SINE*SINE        IFD10020
           *       + XX8*SINE*CCSE*XX11 )  -                               IFD10030
           *       ( CCSE + XX8*SINE )*XX9*XX11*EYE*XKO*SINE  )            IFD10040
            ZZ5 = 0.5*DR*ZZ1                                               IFD10050
            ZZ6 = 1.0 + 0.5*DR*(ZZ2-BEDA1-GAMMA1)                          IFD10060
            ZZ7 = -0.5*DR*ZZ3                                              IFD10070
            ZZ8 = 1.0 - 0.5*DR*(ZZ4-BEDA2-GAMMA2)                          IFD10080
            ZZ9 = 2.0 - ZZ8                                                IFD10090
            ZZ10 = 2.0 - ZZ6                                               IFD10100
C                                                                          IFD10110
C           *** IF BOTTOM SLOPES UP, GO TO 40                              IFD10120
                IF ( ISLOPE.EQ.3 .OR. ISLOPE.EQ.5 ) GO TO 40               IFD10130
C           *** BOTTOM SLOPES DOWN                                         IFD10140
                IFACE2 = IFACEP                                            IFD10150
C               *** COMPUTE OFF-DIAGONAL, Y MATRIX ELEMENTS ON INTERFACE   IFD10160
                    YLI = 0.5 * DR * GAMMA1                                IFD10170
                    YRI = 0.5 * DR * BEDA1                                 IFD10180
C               *** COMPUTE MAIN DIAGONAL, Y MATRIX ELEMENT ON INTERFACE   IFD10190
                    YMI = A(IFACE) * ZZ5  +  ZZ6                           IFD10200
C               *** COMPUTE INTERFACE ELEMENT IN RHS COLUMN VECTOR         IFD10210
                    C(IFACE,4) = U(IFACEM)*YLI + U(IFACE)*YMI +            IFD10220
           *                     U(IFACEP)*YRI                             IFD10230
C               *** COMPUTE X MATRIX ELEMENTS ON INTERFACE                 IFD10240
                    XLI = -0.5 * DR * GAMMA2                               IFD10250
                    XMI = A(IFACE2) * ZZ7  +  ZZ8                          IFD10260
                    XRI = -0.5 * DR * BEDA2                                IFD10270
C                   *** IF MODIFIED BOTTOM THEN NO NEED TO ADJUST LHS      IFD10280
                        IF ( ISLOPE.EQ.4 ) GO TO 45                        IFD10290
                    C(IFACE2,1) = XLI                                      IFD10300
                    C(IFACE2,2) = XMI                                      IFD10310
                    C(IFACE2,3) = XRI                                      IFD10320
C               *** COMPUTE X MATRIX ELEMENTS ONE ROW ABOVE INTERFACE      IFD10330
                    C(IFACE,1) = XLRWS                                     IFD10340
                    C(IFACE,2) = 1.0 - DR * XX1M(IFACE)                    IFD10350
                    C(IFACE,3) = XLRWS                                     IFD10360
                GO TO 60                                                   IFD10370
C                                                                          IFD10380
C           *** BOTTOM SLOPES UP                                           IFD10390
 40             IFACE2 = IFACEM                                           IFD10400
C               *** COMPUTE OFF-DIAGONAL, Y MATRIX ELEMENTS ON INTERFACE   IFD10410
                    YLI = 0.5 * DR * GAMMA2                                IFD10420
                    YRI = 0.5 * DR * BEDA2                                 IFD10430
C               *** COMPUTE MAIN DIAGONAL, Y MATRIX ELEMENT ON INTERFACE   IFD10440
                    YMI = - A(IFACE) * ZZ7  +  ZZ9                         IFD10450
C               *** COMPUTE INTERFACE ELEMENT IN RHS COLUMN VECTOR         IFD10460
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                C(IFACE,4) = U(IFACEM)*YLI + U(IFACE)*YMI +                IFD10470
     *                       U(IFACEP)*YRI                                 IFD10480
C               *** COMPUTE X MATRIX ELEMENTS ON INTERFACE                 IFD10490
                XLI = -0.5 * DR * GAMMA1                                   IFD10500
                XMI = - A(IFACE2) * ZZ5  +  ZZ10                           IFD10510
                XRI = -0.5 * DR * BEDA1                                    IFD10520
C               *** IF MODIFIED BOTTOM THEN NO NEED TO ADJUST LHS          IFD10530
                    IF ( ISLOPE.EQ.5 ) GO TO 45                            IFD10540
                C(IFACE2,1) = XLI                                          IFD10550
                C(IFACE2,2) = XMI                                          IFD10560
                C(IFACE2,3) = XRI                                          IFD10570
C               *** COMPUTE X MATRIX ELEMENTS ONE ROW BELOW INTERFACE      IFD10580
                C(IFACE,1) = XLRWS                                         IFD10590
                C(IFACE,2) = XMS                                           IFD10600
                C(IFACE,3) = XLRWS                                         IFD10610
                GO TO 60                                                   IFD10620
C                                                                          IFD10630
C               *** SAVE INTERFACE VALUES ON SLOPING SECTION               IFD10640
 45             YLIZ = YLI                                                 IFD10650
                YRIZ = YRI                                                 IFD10660
                XLIZ = XLI                                                 IFD10670
                XRIZ = XRI                                                 IFD10680
C                                                                          IFD10690
C               *** SEGMENT LEVEL, COMPUTE MATRIX ELEMENTS ON INTERFACE    IFD10700
 50             IFACE2 = IFACE                                             IFD10710
                YLI = DR * XX6                                             IFD10720
                YMI = 1.0 + DR * ( XX1M(IFACE)/XX4 + XX5 )                 IFD10730
                YRI = DR * XX7                                             IFD10740
                C(IFACE,4) = U(IFACEM)*YLI + U(IFACE)*YMI + U(IFACEP)*YRI  IFD10750
                C(IFACE,1) = -YLI                                          IFD10760
                C(IFACE,2) = 2.0 - YMI                                     IFD10770
                C(IFACE,3) = -YRI                                          IFD10780
C               *** SAVE INTERFACE VALUES ON LEVEL SECTION                 IFD10790
                YLIV = YLI                                                 IFD10800
                YRIV = YRI                                                 IFD10810
C                                                                          IFD10820
 60   CONTINUE                                                             IFD10830
C                                                                          IFD10840
C     *** COMPUTE ARTIFICIAL ATTENUATION MATRIX                            IFD10850
C     *** SEE AESD PE MODEL EY BROCK  -  NORDA TECH NOTE 12  -  JAN 78     IFD10860
C         *** CALCULATE GRID POINT AT TOP OF ART ATTENUATION LAYER         IFD10870
          IA = INT ( ZABLYR/DZ + 0.01 )                                    IFD10880
C         *** CALCULATE NUMBER OF GRID POINTS IN ART ATTENUATION LAYER      IFD10890
          NA = N - IA                                                      IFD10900
C         *** CALCULATE ATTENUATION MATRIX                                 IFD10910
          DO 70 I=1,NA                                                     IFD10920
             TEMP = 3.0 * (I-NA)  /  NA                                    IFD10930
             ATT(I) = EXP(-0.03*DR*EXP(-(TEMP*TEMP)))                      IFD10940
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 70           CONTINUE                                                          IFD10950
C                                                                              IFD10960
C     *** SOLVE FOR SOLUTION FIELD AT RANGE RA2                                IFD10970
          CALL TRIDG (C,U,N,CR,CTWO)                                           IFD10980
C                                                                              IFD10990
C     *** APPLY ARTIFICAL ATTENUTION                                           IFD11000
          CALL ATTENU (U,ATT,IA,NA)                                            IFD11010
C                                                                              IFD11020
      RA2P = RA2 + 0.5                                                         IFD11030
C     *** TIME TO WRITE?                                                       IFD11040
          IF ( RA2P.GE.XWR )  CALL WRITE2                                      IFD11050
C     *** TIME TO PRINT?                                                       IFD11060
          IF ( RA2P.GE.XPR )  CALL PRINT2                                      IFD11070
C                                                                              IFD11080
C     *** UPDATE INTERFACE POINTER                                             IFD11090
          IFACE = IFACE2                                                       IFD11100
C                                                                              IFD11110
      RETURN                                                                   IFD11120
      END                                                                      IFD11130
C                                                                              IFD11140
CCC                                                                            IFD11150
CCC                                                                            IFD11160
C                                                                              IFD11170
      SUBROUTINE TRIDG (C,U,N,CR,CTWO)                                         IFD11180
C                                                                              IFD11190
CCC   *** THIS SUBROUTINE SOLVES A SET OF  N - 1  (NM1)  LINEAR                IFD11200
CCC   *** SIMULTANEOUS EQUATIONS HAVING A TRIDIAGONAL COEFFICIENT              IFD11210
CCC   *** MATRIX.  MATRIX ELEMENTS IN THE LOWER DIAGONAL, MAIN DIAGONAL        IFD11220
CCC   *** AND UPPER DIAGONAL ARE STORED IN C(I,1), C(I,2) AND C(I,3)           IFD11230
CCC   *** RESPECTIVELY.  THE RHS COLUMN VECTOR IS STORED IN C(I,4).            IFD11240
CCC   *** THE SOLUTION FIELD IS STORED IN U(I).                                IFD11250
CCC   ***    (1)  THE INDEX I REFERS TO ROW NUMBER.                            IFD11260
CCC   ***    (2)  WE NEED ONLY SOLVE AN  NM1 X NM1  SYSTEM (RATHER THAN        IFD11270
CCC   ***         AN  N X N  SYSTEM) BECAUSE U(N) IS KNOWN:  U(N)=0.0          IFD11280
CCC   ***    (3)  THE SUBROUTINE IS A MODIFIED VERSION OF SUBROUTINE           IFD11290
CCC   ***         TRIDG FROM:                                                  IFD11300
CCC   ***            "APPLIED NUMERICAL ANALYSIS"    ( SECOND EDITION )      IFD11310
CCC   ***             BY:  CURTIS F. GERALD                                    IFD11320
CCC   ***             PUBLISHED BY ADDISON-WESLEY PUBLISING CO., 1980          IFD11330
CCC   ***    (4)  THE MAIN MODIFICATIONS TO THE ROUTINE IN THE TEXT            IFD11340
CCC   ***         INVOLVED:                                                    IFD11350
CCC   ***        (A)  INTRODUCING ARRAYS CTWO AND CR TO PRESERVE THE           IFD11360
CCC   ***             ORIGINAL VALUES IN C(I,2) AND TO MAKE THE ROUTINE       IFD11370
CCC   ***             MORE EFFICIENT.  THIS RESULTS IN A CONSIDERABLE         IFD11380
CCC   ***             SAVINGS IN EXECUTION TIME FOR THE CASE OF A             IFD11390
CCC   ***             HORIZONTAL BOTTOM.   (SEE SUBROUTINE TRIDL)             IFD11400
CCC   ***        (B)  MODIFYING THE ROUTINE TO SOLVE AN  NM1 X NM1            IFD11410
C     ***             SYSTEM.                                                  IFD11420
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C     ***      (5)  SEE PAGES 129 AND 133 IN THE TEXT FOR FURTHER INFO.   IFD11430
C                                                                         IFD11440
      COMPLEX C(5000,4), U(5000), CR(5000), CTWO(5000)                    IFD11450
C                                                                         IFD11460
      NM1 = N - 1                                                         IFD11470
      NM2 = N - 2                                                         IFD11480
      CTWO(1) = C(1,2)                                                    IFD11490
      DO 10 I=2,NM1                                                       IFD11500
         CR(I) = C(I,1) / CTWO(I-1)                                       IFD11510
         CTWO(I) = C(I,2) - CR(I) * C(I-1,3)                              IFD11520
         C(I,4)  = C(I,4) - CR(I) * C(I-1,4)                              IFD11530
   10 CONTINUE                                                            IFD11540
C                                                                         IFD11550
      U(N) = 0.0                                                          IFD11560
C                                                                         IFD11570
C     *** NOW PERFORM BACK SUBSTITUTION                                   IFD11580
C                                                                         IFD11590
      U(NM1) = C(NM1,4) / CTWO(NM1)                                       IFD11600
      DO 20 I=1,NM2                                                       IFD11610
         M = NM1 - I                                                      IFD11620
         U(M) = ( C(M,4)-C(M,3)*U(M+1) ) / CTWO(M)                        IFD11630
   20 CONTINUE                                                            IFD11640
C                                                                         IFD11650
      RETURN                                                              IFD11660
      END                                                                 IFD11670
C                                                                         IFD11680
C                                                                         IFD11690
C                                                                         IFD11700
C                                                                         IFD11710
      SUBROUTINE TRIDI (C,U,N,CR,CTWO)                                    IFD11720
C                                                                         IFD11730
C     *** THIS SUBROUTINE IS A MODIFIED VERSION OF SUBROUTINE TRIDG       IFD11740
C     *** FROM THE IFD PROGRAM. SUBROUTINE TRIDG IS IN TURN A MODIFIED    IFD11750
C     *** VERSION OF TRIDG AS PER THE REFERENCE BELOW.                    IFD11760
C     *** THE SUBROUTINE SOLVES A SET OF  N - 1  (NM1)  LINEAR            IFD11770
C     *** SIMULTANEOUS EQUATIONS HAVING A TRIDIAGONAL COEFFICIENT         IFD11780
C     *** MATRIX.  MATRIX ELEMENTS IN THE LOWER DIAGONAL, MAIN DIAGONAL   IFD11790
C     *** AND UPPER DIAGONAL ARE STORED IN C(I,1), C(I,2) AND C(I,3)      IFD11800
C     *** RESPECTIVELY.  THE RHS COLUMN VECTOR IS STORED IN C(I,4).       IFD11810
C     *** THE SOLUTION FIELD IS STORED IN U(I).                           IFD11820
C     ***    (1)  THE INDEX I REFERS TO ROW NUMBER.                       IFD11830
C     ***    (2)  WE NEED ONLY SOLVE AN  NM1 X NM1  SYSTEM (RATHER THAN   IFD11840
C     ***         AN  N X N  SYSTEM) BECAUSE U(N) IS KNOWN:  U(N)=0.0     IFD11850
C     ***    (3)  THE SUBROUTINE IS A MODIFIED VERSION OF IFD SUB-        IFD11860
C     ***         ROUTINE TRIDG WHICH IN TURN IS A MODIFIED VERSION       IFD11870
C     ***         OF SUBROUTINE TRIDG AS PER:                             IFD11880
C     ***            "APPLIED NUMERICAL ANALYSIS"   ( SECOND EDITION )    IFD11890
C     ***             BY:  CURTIS F. GERALD                               IFD11900
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C     ***                PUBLISHED BY ADDISON-WESLEY PUBLISHING CO., 1980    IFD11910
C     ***     (4)  THE ONLY MODIFICATION TO IFD SUBROUTINE TRIDG IS          IFD11920
C     ***          THAT TRIDI DOES NOT RECALCULATE CTWO AND CR, BUT          IFD11930
C     ***          BUT RATHER TRIDL USES THE ARRAY VALUES CALCULATED         IFD11940
C     ***          BY TRIDG.  THIS RESULTS IN A CONSIDERABLE SAVINGS         IFD11950
C     ***          IN EXECUTION TIME FOR THE CASE OF A HORIZONTAL            IFD11960
C     ***          BOTTOM.                                                   IFD11970
C                                                                            IFD11980
      COMPLEX C(5000,4), U(5000), CR(5000), CTWO(5000)                       IFD11990
C                                                                            IFD12000
      NM1 = N - 1                                                            IFD12010
      NM2 = N - 2                                                            IFD12020
      DO 10 I=2,NM1                                                          IFD12030
         C(I,4) = C(I,4) - CR(I) * C(I-1,4)                                  IFD12040
   10 CONTINUE                                                               IFD12050
C                                                                            IFD12060
      U(N) = 0.0                                                             IFD12070
C                                                                            IFD12080
C     *** NOW PERFORM BACK SUBSTITUTION                                      IFD12090
C                                                                            IFD12100
      U(NM1) = C(NM1,4) / CTWO(NM1)                                          IFD12110
      DO 20 I=1,NM2                                                          IFD12120
         M = NM1 - I                                                         IFD12130
         U(M) = ( C(M,4)-C(M,3)*U(M+1) ) / CTWO(M)                           IFD12140
   20 CONTINUE                                                               IFD12150
C                                                                            IFD12160
      RETURN                                                                 IFD12170
      END                                                                    IFD12180
C                                                                            IFD12190
C                                                                            IFD12200
C                                                                            IFD12210
C                                                                            IFD12220
      SUBROUTINE DOWN                                                        IFD12230
C                                                                            IFD12240
C     THIS SUBROUTINE UPDATES THE RHS & LHS OF THE EQUATION AND              IFD12250
C     SOLVES FOR THE SOLUTION FIELD AT RA2.                                  IFD12260
C        (1)  THE RHS COLUMN VECTOR VALUES ARE STORED IN C(I,4)              IFD12270
C        (2)  THE INTERFACE AT RANGE RA1 IS AT GRIDPOINT IFACE               IFD12280
C        (3)  THE INTERFACE AT RANGE RA2 IS AT GRIDPOINT IFACE2              IFD12290
C                ( WHERE IFACE2 = IFACE + 1 )                                IFD12300
C                                                                            IFD12310
      COMPLEX A,A2,C,CR,CTWO,EYE,                                            IFD12320
     *        XLI,XLI2,XLRWS,XMI,XMS,XRI,XRI2,                               IFD12330
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,                     IFD12340
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,                 IFD12350
     *        U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                     IFD12360
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBOT,NM1,         IFD12370
     *        NSTEP,NSTEP1,NSVF,NWMAX,NXLFS                                  IFD12380
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      COMMON /REAL/ ALPHA,AIT(5000),BETA1,BETA2,BR(101),BZ(101),C0,      IFD12390
     *        CSVP(101),C2,CWATER(5000),DR,DRIVL,DRMAX,DZ,FRQ,FDR,FDZ,   IFD12400
     *        R1,RA1,RA2,RHC1,RHO2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,   IFD12410
     *        XX11,XWB,WDR,ZIYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR             IFD12420
      COMMON /CPLX/  A(5000),A2,C(5000,4),CR(5000),CTWC(5000),           IFD12430
     *        EYE,XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                       IFD12440
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),           IFD12450
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,       IFD12460
     *        U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                           IFD12470
C                                                                        IFD12480
C     *** UPDATE IFACE2                                                  IFD12490
      IFACE2 = IFACE + 1                                                 IFD12500
C     *** UPDATE Y MATRIX, MAIN DIAGONAL, INTERFACE ELEMENT              IFD12510
      YMI = A(IFACE) * ZZ5  +  ZZ6                                       IFD12520
C     *** UPDATE Y MATRIX, MAIN DIAGONAL, WATER ELEMENT, ONE ROW         IFD12530
C     *** ABOVE INTERFACE                                                IFD12540
      YMW(IFACE-1) = 1.0 + DR * XX1M(IFACE-1)                            IFD12550
C                                                                        IFD12560
C     *** UPDATE RHS                                                     IFD12570
      CALL RHS                                                           IFD12580
C     *** UPDATE LHS                                                     IFD12590
C        *** UPDATE X MATRIX ELEMENTS ONE ROW ABOVE INTERFACE            IFD12600
         C(IFACE,1) = XLRWS                                              IFD12610
         C(IFACE,2) = 1.0 - DR*XX1M(IFACE)                               IFD12620
         C(IFACE,3) = XLRWS                                              IFD12630
C        *** UPDATE X MATRIX ELEMENTS ON INTERFACE                       IFD12640
         C(IFACE2,1) = XLI                                               IFD12650
         C(IFACE2,2) = A(IFACE2) * ZZ7  +  ZZ8                           IFD12660
         C(IFACE2,3) = XRI                                               IFD12670
C                                                                        IFD12680
C     *** SOLVE THE TRIDIAGONAL SYSTEM                                   IFD12690
      CALL TRIDG (C,U,N,CR,CTWO)                                         IFD12700
C     *** UPDATE IFACE                                                   IFD12710
      IFACE = IFACE2                                                     IFD12720
      RETURN                                                             IFD12730
      END                                                                IFD12740
C                                                                        IFD12750
CC                                                                       IFD12760
CC                                                                       IFD12770
C                                                                        IFD12780
      SUBROUTINE UP                                                      IFD12790
C                                                                        IFD12800
C     THIS SUBROUTINE UPDATES THE RHS & LHS OF THE EQUATION AND          IFD12810
C     SOLVES FOR THE SOLUTION FIELD AT RA2.                              IFD12820
C        (1)  THE RHS COLUMN VECTOR VALUES ARE STORED IN C(I,4)          IFD12830
C        (2)  THE INTERFACE AT RANGE RA1 IS AT GRIDPOINT IFACE           IFD12840
C        (3)  THE INTERFACE AT RANGE RA2 IS AT GRIDPOINT IFACE2          IFD12850
C                ( WHERE IFACE2 = IFACE - 1 )                            IFD12860
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C                                                                       IFD12870
      COMPLEX A,A2,C,CR,CTWC,EYE,                                       IFD12880
     *        XLI,XLI2,XLRWS,XMI,XMS,XRI,XRIZ,                           IFD12890
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,                 IFD12900
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,             IFD12910
     *        U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                 IFD12920
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IW2,N,NA,NBCT,NM1,    IFD12930
     *        NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                             IFD12940
      COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,     IFD12950
     *        CSVP(101),C2,CWATER(5000),DR,DRIVL,DRMAX,DZ,FRQ,FDR,FDZ,  IFD12960
     *        R1,RA1,RA2,RHO1,RHO2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,   IFD12970
     *        XX11,XZF,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR            IFD12980
      COMMON /CPLX/  A(5000),A2,C(5000,4),CR(5000),CTWO(5000),          IFD12990
     *        EYE,XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                      IFD13000
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),          IFD13010
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,      IFD13020
     *        U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                          IFD13030
C                                                                       IFD13040
C     *** UPDATE IFACE2                                                 IFD13050
      IFACE2 = IFACE - 1                                                IFD13060
C     *** UPDATE Y MATRIX, MAIN DIAGONAL, INTERFACE ELEMENT             IFD13070
      YMI = -A(IFACE) * ZZ7  +  ZZ9                                     IFD13080
C     *** UPDATE RHS                                                    IFD13090
      CALL RHS                                                          IFD13100
C     *** UPDATE LHS                                                    IFD13110
C        *** UPDATE X MATRIX ELEMENTS ONE ROW BELOW INTERFACE           IFD13120
         C(IFACE,1) = XLRWS                                             IFD13130
         C(IFACE,2) = XMS                                               IFD13140
         C(IFACE,3) = XLRWS                                             IFD13150
C        *** UPDATE X MATRIX ELEMENTS ON INTERFACE                      IFD13160
         C(IFACE2,1) = XLI                                              IFD13170
         C(IFACE2,2) = -A(IFACE2) * ZZ5  +  ZZ10                        IFD13180
         C(IFACE2,3) = XRI                                              IFD13190
C                                                                       IFD13200
C     *** SOLVE THE TRIDIAGONAL SYSTEM                                  IFD13210
      CALL TRIDG (C,U,N,CR,CTWO)                                        IFD13220
C     *** UPDATE IFACE                                                  IFD13230
      IFACE = IFACE2                                                    IFD13240
      RETURN                                                            IFD13250
      END                                                               IFD13260
C                                                                       IFD13270
CC                                                                      IFD13280
CC                                                                      IFD13290
C                                                                       IFD13300
      SUBROUTINE SSLOPE                                                 IFD13310
C                                                                       IFD13320
CC    *** THIS SUBROUTINE IS CALLED TO ADVANCE THE SOLUTION FIELD       IFD13330
C     *** FOR THE CASE OF A MODIFIED BOTTOM.                            IFD13340
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C      ***    (1)   THIS CASE CCCURS WHEN THE BOTTOM SLCPE IS TOC SMALL     IFD13350
C      ***          FOR THE MAXIMUM RANGE STEP.                            IFD13360
C      ***    (2)   THIS SUBROUTINE WORKS FOR BOTH A DCWNSIOPE AND         IFD13370
C      ***          UPSICPE MODIFIED BOTTOM.                               IFD13380
C      ***    (3)   THE SUBROUTINE DETERMINES WHICH OF THE FCLLCWING       IFD13390
C      ***          THREE TYPES CF BOTTOM SECTIONS NEEDS TC BE CCNSILERED: IFD13400
C      ***             (A) LEVEL SECTION FOLLOWS IEVEL SECTION             IFD13410
C      ***             (B) LEVEL SECTION FOLLOWS SLOPING SECTION           IFD13420
C      ***             (C) SLOPING SECTION.                                IFD13430
C      ***    (4)   AFTER DETERMINING WHICH OF THE THREE TYPES OF BOTTCM   IFD13440
C      ***          SECTICNS IS APPROPRIATE, THE SUBROUTINE MAKES MATRIX   IFD13450
C      ***          ELEMENT CHANGES AS REQUIRED AND CALLS CN OTHER         IFD13460
C      ***          SUBFCUTINES TC ADVANCE THE SOLUTICN.                   IFD13470
C                                                                          IFD13480
       CCMPLEX A,A2,C,CR,CTWC,EYE,                                         IFD13490
      *        XL1,XL1Z,XLRWS,XMI,XMS,XRI,XRIZ,                           IFD13500
      *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,                 IFD13510
      *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,             IFD13520
      *        U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                 IFD13530
       CCMMCN /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBCT,NM1,      IFD13540
      *        NSTEP,NSTEP1,NSVE,NWMAX,NXLFS                              IFD13550
       CCMMCN /REAL/ AIPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,       IFD13560
      *        CSVP(101),C2,CWATER(5000),DR,DRIVL,DRMAX,DZ,FRQ,FDR,FDZ,   IFD13570
      *        R1,RA1,RA2,RHC1,RHC2,RMAX,THETA,XK0,XLAMLA,XPR,XX4,XX10,   IFD13580
      *        XX11,XWB,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAEIYR            IFD13590
       CCMMCN /CPIX/  A(5000),A2,C(5000,4),CR(5000),CTWC(5000),           IFD13600
      *        EYE,XL1,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                       IFD13610
      *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),           IFD13620
      *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,       IFD13630
      *        U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                           IFD13640
C                                                                          IFD13650
C      *** IS THIS A IEVEL SECTICN FOLLOWING A SLOPING SECTION?            IFD13660
           IF (ISTEP.EQ.NXLFS)  GC TO 20                                   IFD13670
C      *** NC                                                              IFD13680
C                                                                          IFD13690
C      *** IS THIS A SIOPING SECTION?                                      IFD13700
           ITEST = NXIFS - ISTEF                                           IFD13710
           IF (ITEST.EQ.1) GC TC 30                                        IFD13720
C      *** NC                                                              IFD13730
C                                                                          IFD13740
C      *** IEVEL SECTICN FOLICWS A LEVEL SECTION                           IFD13750
           CALL IEVEL                                                      IFD13760
           GC TO 50                                                        IFD13770
C                                                                          IFD13780
C      *** LEVEL SECTICN FOLLCWS A SLOPING SECTION                         IFD13790
C          *** UPDATE NXLFS                                                IFD13800
 20            NXIFS = NXLFS + NSTEP1                                      IFD13810
C          *** IF LAST SECTICN SLCPED DOWN, UPDATE Y MATRIX ELEMENT,       IFD13820
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C           *** MAIN DIAGONAL, IN WATER, ONE ROW ABOVE INTERFACE                IFD13830
                IF ( ISLOPE.EQ.5 ) GO TO 25                                     IFD13840
                YMW(IFACE-1) = 1.0 + DR * XX1M(IFACE-1)                         IFD13850
C           *** UPDATE RHS INTERFACE ELEMENTS                                   IFD13860
 25             YLI = YLIV                                                      IFD13870
                YMI = 1.0 + DR * ( XX1M(IFACE)/XX4 + XX5 )                      IFD13880
                YRI = YRIV                                                      IFD13890
C           *** UPDATE LHS                                                      IFD13900
                C(IFACE,1) = -YLI                                               IFD13910
                C(IFACE,2) = 2.0 - YMI                                          IFD13920
                C(IFACE,3) = -YRI                                               IFD13930
C           *** SOLVE SYSTEM                                                    IFD13940
                CALL RHS                                                        IFD13950
                CALL TRIDG(C,U,N,CR,CTWO)                                       IFD13960
            GO TO 50                                                            IFD13970
C                                                                               IFD13980
C       *** SLOPING SECTION                                                     IFD13990
C           *** UPDATE INTERFACE ELEMENTS                                       IFD14000
 30             YLI = YLIZ                                                      IFD14010
                YRI = YRIZ                                                      IFD14020
                XLI = XLIZ                                                      IFD14030
                XRI = XRIZ                                                      IFD14040
C           *** SOLVE SYSTEM AS APPROPRIATE                                     IFD14050
                IF (ISLOPE.EQ.4) CALL DOWN                                      IFD14060
                IF (ISLOPE.EQ.5) CALL UP                                        IFD14070
C                                                                               IFD14080
 50     CONTINUE                                                                IFD14090
        RETURN                                                                  IFD14100
        END                                                                     IFD14110
C                                                                               IFD14120
CC                                                                              IFD14130
C                                                                               IFD14140
C                                                                               IFD14150
        SUBROUTINE RHS                                                          IFD14160
C                                                                               IFD14170
C       THIS SUBROUTINE MULTIPLIES TRIDIAGONAL MATRIX Y TIMES SOLUTION          IFD14180
C       FIELD U TO OBTAIN AN UPDATED RHS.                                       IFD14190
C          (1)  THE RHS COLUMN VECTOR VALUES ARE STORED IN C(I,4).              IFD14200
C                                                                               IFD14210
        COMPLEX A,A2,C,CR,CTWO,EYE,                                             IFD14220
     *          XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                                IFD14230
     *          XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,                      IFD14240
     *          YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,                  IFD14250
     *          U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                      IFD14260
        COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBC1,NM1,          IFD14270
     *          NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                                   IFD14280
        COMMON /REAL/ ALPHA,AIT(5000),BETA1,BETA2,BR(101),BZ(101),C0,           IFD14290
     *          CSVP(101),C2,CWATER(5000),DR,DRLVL,DRMAX,DZ,FRQ,HDR,HDZ,       IFD14300
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     *         R1,RA1,FA2,RHC1,BHO2,RMAX,THETA,XKO,XLAMDA,XPR,XX4,XX10,    IFD14310
     *         XX11,XWF,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAEIYR             IFD14320
      COMMON /CPLX/  A(5000),A2,C(5000,4),CR(5000),CTWC(5000),            IFD14330
     *         EYE,XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                        IFD14340
     *         XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),            IFD14350
     *         YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,        IFD14360
     *         U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                            IFD14370
C                                                                          IFD14380
C     *** UPDATE IFACEM & IFACEP                                           IFD14390
          IFACEM = IFACE - 1                                               IFD14400
          IFACEP = IFACE + 1                                               IFD14410
C     *** UPDATE RHS                                                       IFD14420
          C(1,4) = U(1) * YMW(1)   +  U(2) * YLRWS                         IFD14430
          DO 10 I=2,IFACEM                                                 IFD14440
             C(I,4) = U(I) * YMW(I)   +  (U(I-1)+U(I+1)) * YLRWS           IFD14450
       10 CONTINUE                                                         IFD14460
          C(IFACE,4) = U(IFACEM)*YLI + U(IFACE)*YMI + U(IFACEP)*YRI        IFD14470
          DO 20 I=IFACEP,NM1                                               IFD14480
             C(I,4) = U(I)*YMS + (U(I-1)+U(I+1))*YLRWS                     IFD14490
       20 CONTINUE                                                         IFD14500
C                                                                          IFD14510
          RETURN                                                           IFD14520
          END                                                              IFD14530
C                                                                          IFD14540
C                                                                          IFD14550
C                                                                          IFD14560
C                                                                          IFD14570
      SUBROUTINE LEVEL                                                     IFD14580
C                                                                          IFD14590
C     THIS SUBROUTINE UPDATES THE RHS OF THE EQUATION AND SOLVES           IFD14600
C     FOR THE SOLUTION FIELD AT RANGE RA2.                                 IFD14610
C        (1)  THE RHS COLUMN VECTOR VALUES ARE STORED IN C(I,4).           IFD14620
C        (2)  FOR THE LEVEL INTERFACE THE LHS TRIDIAGINAL MATRIX           IFD14630
C             ELEMENTS NEED NOT BE UPDATED.                                IFD14640
C                                                                          IFD14650
      COMPLEX A,A2,C,CR,CTWC,EYE,                                          IFD14660
     *         XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                            IFD14670
     *         XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,                  IFD14680
     *         YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,              IFD14690
     *         U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                  IFD14700
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBOT,NM1,       IFD14710
     *         NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                               IFD14720
      COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),CO,        IFD14730
     *         CSVP(101),C2,CWATER(5000),DR,DRIVL,DRMAX,DZ,FRQ,FDR,FDZ,    IFD14740
     *         R1,RA1,FA2,RHC1,BHO2,RMAX,THETA,XKO,XLAMDA,XPR,XX4,XX10,    IFD14750
     *         XX11,XWF,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAEIYR             IFD14760
      COMMON /CPLX/  A(5000),A2,C(5000,4),CR(5000),CTWC(5000),            IFD14770
     *         EYE,XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                        IFD14780
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     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),                IFD14790
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,            IFD14800
     *        U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                IFD14810
C                                                                            IFD14820
C     *** UPDATE RHS                                                         IFD14830
      CALL RHS                                                               IFD14840
C                                                                            IFD14850
C     *** SOLVE THE TRIDIAGONAL SYSTEM                                       IFD14860
      CALL TRIDL (C,U,N,CR,CTWO)                                             IFD14870
C                                                                            IFD14880
      RETURN                                                                 IFD14890
      END                                                                    IFD14900
C                                                                            IFD14910
CC                                                                           IFD14920
CCC                                                                          IFD14930
C                                                                            IFD14940
      SUBROUTINE PRINT2                                                      IFD14950
C                                                                            IFD14960
CC       (1)  THIS SUBROUTINE IS EFFECTIVELY THE CONTINUATION OF             IFD14970
CC            SUBROUTINE PRINT1.                                             IFD14980
CC       (2)  THE FILE CREATED CORRESPONDS TO UNIT FILE NUMBER:              IFD14990
CC            NPOUT = 55.                                                    IFD15000
CC       (3)  THE FILENAME AND FILETYPE FOR THIS FILE ARE:                   IFD15010
CCC               IFIOUT    PRINTER                                        IFD15020
C                                                                            IFD15030
      DIMENSION PRMAG(5000),PIFD(121,121)                                    IFD15040
      COMPLEX A,A2,C,CR,CTWO,EYE,                                            IFD15050
     *        XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                               IFD15060
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,                     IFD15070
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,                 IFD15080
     *        U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                     IFD15090
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IWZ,N,NA,NBOT,NM1,         IFD15100
     *        NSTEP,NSTEP1,NSVP,NWMAX,NXLFS,IR                               IFD15110
      COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),CC,          IFD15120
     *        CSVP(101),C2,CWATER(5000),DR,DRIVL,DRMAX,DZ,FRQ,FDR,FDZ,       IFD15130
     *        R1,RA1,RA2,RHO1,RHO2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,       IFD15140
     *        XX11,XWF,WDR,ZIYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR,               IFD15150
     *        PIFD                                                           IFD15160
      COMMON /CPLX/  A(5000),A2,C(5000,4),CR(5000),CTWO(5000),               IFD15170
     *        EYE,XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                           IFD15180
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),               IFD15190
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,           IFD15200
     *        U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                               IFD15210
      DATA NPOUT/55/                                                         IFD15220
C                                                                            IFD15230
C     *** PRINT RANGE                                                        IFD15240
      IF((RA2.LT. 1398.0).OR.(RA2 .GT. 2002.0)) GO TO 30                     IFD15250
C     IF(RA2 .GT. 2102.0) GO TO 30                                           IFD15260
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C           WRITE(NPOUT,900) RA2                                              IFD15270
            IR = IR + 1                                                       IFD15280
C                                                                             IFD15290
C       *** COMPUTE AND PRINT PROPAGATION LOSS AT EACH IPZ'TH DEPTH           IFD15300
            WRITE(NPOUT,901)                                                  IFD15310
            II = 0                                                            IFD15320
            DO 20 I=IPZ,N,IPZ                                                 IFD15330
               ZI = I*DZ                                                      IFD15340
C              IZL1 = INT(ZLYR1)                                              IFD15350
               PL = CABS(U(I))                                                IFD15360
               IF ( PL.LE.0.0 ) GO TO 10                                      IFD15370
               PL = -20.0*ALOG10(PL) + 10.0*ALOG10(RA2)                       IFD15380
               GO TO 15                                                       IFD15390
   10          PL = 999.9                                                     IFD15400
   15          CONTINUE                                                       IFD15410
               PRMAG(I) = CABS(U(I))                                          IFD15420
C              IF(ZI .GT. ZLYR1)GO TO 20                                      IFD15430
               IF(ZI .GT.121.0)GO TO 20                                       IFD15440
C              WRITE(NPOUT,902)  ZI, PL, PRMAG(I)                             IFD15450
               II = II + 1                                                    IFD15460
C              DIFD(II,IR) = PL                                               IFD15470
               PIFD(II,IR) = PRMAG(I)*100                                     IFD15480
   20          CONTINUE                                                       IFD15490
   30          CONTINUE                                                       IFD15500
C        IF(RA2.GT.1990.0)WRITE(31,36)(ATT(I),I=1,4000)                       IFD15510
C36      FORMAT(7F10.5)                                                       IFD15520
C                                                                             IFD15530
C       *** DETERMINE NEXT RANGE AT WHICH TO PRINT SOLUTION                   IFD15540
            XPR = XPR+FIR                                                     IFD15550
C                                                                             IFD15560
  900   FORMAT(///,5X,'RANGE =',F9.3,' M',/)                                  IFD15570
  901   FORMAT(15X,'DEPTH',6X,'LOSS(DB)',14X,'PRMAG(I)',/)                    IFD15580
  902   FORMAT(10X,F10.2,3X,F10.2,13X,E12.5)                                  IFD15590
C                                                                             IFD15600
        RETURN                                                                IFD15610
        END                                                                   IFD15620
C                                                                             IFD15630
C                                                                             IFD15640
C                                                                             IFD15650
C                                                                             IFD15660
        SUBROUTINE WRITE2                                                     IFD15670
C                                                                             IFD15680
C           (1)  THIS SUBROUTINE IS EFFECTIVELY THE CONTINUATION OF           IFD15690
C                SUBROUTINE WRITE1                                            IFD15700
C           (2)  THE SUBROUTINE WRITES RANGE, RECEIVER DEPTH AND U(I)         IFD15710
C                WHEN CALLED.  IT THEN UPDATES THE NEXT WRITE RANGE (XWR).    IFD15720
C           (3)  THE FILE WRITTEN INTO CORRESPONDS TO UNIT FILE NUMBER:       IFD15730
C                NOU = 52.                                                    IFD15740
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C         (4)  THE FILENAME AND FILETYPE FOR THIS FILE ARE:                  IFD15750
C                  IFICUT   FLCTTER                                          IFD15760
C                                                                            IFD15770
      COMPLEX A,A2,C,CR,CTWC,EYE,                                            IFD15780
     *        XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                                IFD15790
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M,                      IFD15800
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW,YRI,YRIV,YRIZ,                  IFD15810
     *        U,ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                                      IFD15820
      COMMON /IN/ IA,IBOT1,IFACE,IPZ,ISLOPE,ISTEP,IW2,N,NA,NBCT,NM1,         IFD15830
     *        NSTEP,NSTEP1,NSVP,NWMAX,NXLFS                                  IFD15840
      COMMON /REAL/ ALPHA,ATT(5000),BETA1,BETA2,BR(101),BZ(101),C0,          IFD15850
     *        CSVP(101),C2,CWATER(5000),DR,DRLVL,DRMAX,DZ,FRQ,FDR,FDZ,       IFD15860
     *        R1,RA1,RA2,RHC1,RHC2,RMAX,THETA,XK0,XLAMDA,XPR,XX4,XX10,       IFD15870
     *        XX11,XWR,WDR,ZLYR1,ZLYR2,ZR,ZS,ZSVP(101),ZAELYR                 IFD15880
      COMMON /CPIX/  A(5000),A2,C(5000,4),CR(5000),CTWC(5000),               IFD15890
     *        EYE,XLI,XLIZ,XLRWS,XMI,XMS,XRI,XRIZ,                           IFD15900
     *        XX1,XX2,XX3,XX5,XX6,XX7,XX8,XX9,XX12,XX1M(5000),               IFD15910
     *        YLI,YLIV,YLIZ,YLRWS,YMI,YMS,YMW(5000),YRI,YRIV,YRIZ,           IFD15920
     *        U(5000),ZZ5,ZZ6,ZZ7,ZZ8,ZZ9,ZZ10                               IFD15930
      DATA NOU/52/                                                           IFD15940
C                                                                            IFD15950
C     *** WRITE RANGE, DEPTH AND U(I)                                        IFD15960
          WRITE(NOU,*)  RA2, ZR, U(IW2)                                      IFD15970
C                                                                            IFD15980
C     *** DETERMINE NEXT RANGE AT WHICH TO WRITE SOLUTION                    IFD15990
          XWR = XWR+WDR                                                      IFD16000
C                                                                            IFD16010
      RETURN                                                                 IFD16020
      END                                                                    IFD16030
C                                                                            IFD16040
C                                                                            IFD16050
C                                                                            IFD16060
C                                                                            IFD16070
      SUBROUTINE ATTENU(U,ATT,IA,NA)                                         IFD16080
C                                                                            IFD16090
C     THIS SUBROUTINE APPLIES ARTIFICIAL ATTENUATION TO THE BOTTOM-          IFD16100
C     MOST NA GRID POINTS AS PER AESD PE MODEL BY BROCK  -  NORDA            IFD16110
C     TECH NOTE 12  -  JAN 78                                                IFD16120
C          (1)  ATTENUATION  MATRIX ATT IS CALCULATED IN SUBROUTINE          IFD16130
C               NEWMAT                                                       IFD16140
C                                                                            IFD16150
      COMPLEX U(5000)                                                        IFD16160
      DIMENSION ATT(5000)                                                    IFD16170
C                                                                            IFD16180
      DO 10 I=1,NA                                                           IFD16190
         U(IA+I) = U(IA+I)  * ATT(I)                                         IFD16200
 10   CONTINUE                                                               IFD16210
C                                                                            IFD16220
```

```
      RETURN                                                            IFD16230
      END                                                               IFD16240
C                                                                       IFD16250
C                                                                       IFD16260
C                                                                       IFD16270
C                                                                       IFD16280
      SUBROUTINE END (RA2)                                              IFD16290
C                                                                       IFD16300
C     THIS SUBROUTINE IS CALLED WHEN THE SOLUTION FIELD HAS REACHED     IFD16310
C     THE MAXIMUM RANGE SPECIFIED (RMAX).  THE SUBROUTINE SENDS         IFD16320
C     APPROPRIATE MESSAGES TO THE TERMINAL AND STOPS EXECUTION.         IFD16330
C                                                                       IFD16340
      WRITE(6,899) RA2                                                  IFD16350
      WRITE(6,900)                                                      IFD16360
      WRITE(6,901)                                                      IFD16370
C                                                                       IFD16380
      STOP                                                              IFD16390
  899 FORMAT(/,' THE PROGRAM HAS REACHED RANGE R =',F8.1,' METERS.')    IFD16400
  900 FORMAT (' ///,                                                    IFD16410
     *   5X,'END OF RUN',//,                                          IFD16420
     *  10X,'(1)  OUTPUT PRINTER FILE:',//,                           IFD16430
     *  15X,'(A)  A FILE WITH FORMATTED OUTPUT HAS BEEN GENERATED.',//,IFD16440
     *  15X,'(B)  THIS FILE IS READY TO BE SENT TO THE PRINTER.',//,  IFD16450
     *  15X,'(C)  THE FILENAME AND FILETYPE FOR THIS FILE ARE:',//,   IFD16460
     *  15X,'         IFDOUT        PRINTER',///,                     IFD16470
     *  10X,'(2)  OUTPUT PLOTTER FILE:',//,                           IFD16480
     *  15X,'(A)  A FILE WITH UNFORMATTED OUTPUT HAS BEEN GENERATED.',//,IFD16490
     *  15X,'(B)  THIS FILE CONTAINS INPUT DATA FOR THE PLOT ROUTINE.',//,IFD16500
     *  15X,'(C)  THE FILENAME AND FILETYPE FOR THIS FILE ARE:',//,   IFD16510
     *  15X,'         IFDOUT        PLOTTER',//,                      IFD16520
     *  15X,'(D)  THE FILENAME AND FILETYPE FOR THE PLOT ROUTINE ARE:',//,IFD16530
     *  15X,'         PLOTIFD       FORTRAN ')                        IFD16540
  901 FORMAT (                                                          IFD16550
     *  15X,'(E)  TO PLOT THE DATA, GO TO A GRAPHICS TERMINAL AND',//, IFD16560
     *  15X,'     ENTER COMMANDS AS FOLLOWS:',//,                     IFD16570
     *  15X,'           DEF STOR 1M     ',//,                        IFD16580
     *  15X,'           I CMS           ',//,                        IFD16590
     *  15X,'           FORTGI PLOTIFD  ',//,                        IFD16600
     *  15X,'           PLOTIFD         ',//,                        IFD16610
     *  15X,'     THEN FOLLOW PROGRAM PROMPTS.')                      IFD16620
C                                                                       IFD16630
      RETURN                                                            IFD16640
      END                                                               IFD16650
```

```
C     ********************************************** **********************PLO00010
CC    ************************************************************************PLO00020
CC    **                                                                    **PLO00030
CC    **  THE FOLLOWING IS A GRAPHICS PACKAGE TO DO CONTOURING              **PLO00040
CC    **                                                                    **PLO00050
CC    ********************************************** **********************PLO00060
CC    ************************************************************************PLO00070
CC    **                                                                    **PLO00080
CC    **  BY MARK E. KOSNIK                                                 **PLO00090
CC    **  U.S. NAVAL POSTGRADUATE SCHOOL                                    **PLO00100
CC    **  MONTEREY, CA  93943                                               **PLO00110
CC    **                                                                    **PLO00120
CC    ********************************************** **********************PLO00130
CC    ************************************************************************PLO00140
CC    ************************************************************************PLO00150
CC    **  ALPHABETICAL LISTING OF VARIABLES                                 **PLO00160
CC    ************************************************************************PLO00170
CC    **  A    - ARRAY TO STORE VALUES TO BE CONTOURED                      **PLO00180
CC    **  DATA - ARRAY TO STORE VALUES READ IN FROM IFD PROGRAM             **PLO00190
CC    **  N    - INTEGER VALUE FOR NUMBER OF DEPTH INCREMENTS               **PLO00200
CC    ************************************************************************PLO00210
C                                                                            PLO00220
      DIMENSION VARIABLES(MUST USE A SQUARE ARRAY FOR PROPER CONTOURING)     PLO00230
      REAL DATA(121,121),A(121,121)                                          PLO00240
      INTEGER N/121/                                                         PLO00250
C                                                                            PLO00260
      COMMON       WORK(20000)                                             PLO00270
C                                                                            PLO00280
C     READ IN TL VALUES GENERATED BY THE IFD.                                PLO00290
      READ(21,600) ((DATA(I,J),J=1,N),I=1,N)                                 PLO00300
600   FORMAT(10F7.2)                                                         PLO00310
      READ(27,600) ((DATA(I,J),J=1,N),I=1,N)                                 PLO00320
                                                                             PLO00330
C                                                                            PLO00340
C     MANIPULATE ARRAY IN PROPER FORMAT TO BE CONTOURED.                     PLO00350
      DO 10 I = 1,N                                                          PLO00360
      II = N - (I-1)                                                         PLO00370
      DO 20 J = 1,N                                                          PLO00380
```

```
      A(J,I) = DATA(II,J)                                                PL000390
20    CONTINUE                                                           PL000400
10    CONTINUE                                                           PL000410
C                                                                        PL000420
C     PLOTTING/GRAPHICS ROUTINE.                                         PL000430
      CALL TEK618                                                        PL000440
C     CALL COMPRS                                                        PL000450
      CALL PAGE(11.0,8.5)                                                PL000460
C     CALL PLOWUP(1.25)                                                  PL000470
      CALL AREA2D(8.0,6.0)                                               PL000480
      CALL HEIGHT(.2)                                                    PL000490
      CALL XNAME('(R)ANGE (()M())$',100)                                 PL000500
      CALL YNAME('(D)EPTH (()M())$',100)                                 PL000510
      CALL SWISSM                                                        PL000520
C     CALL SHDCHR(90.,1,.002,1)                                          PL000530
      CALL HEIGHT(.35)                                                   PL000540
      CALL BASALF('L/CST')                                               PL000550
      CALL MIXALF('STAND')                                               PL000560
C     CALL HEADIN('(II C)ONTOURS$',100,1.,1)                             PL000570
      CALL HEIGHT(.2)                                                    PL000580
C     CALL MESSAG('(F)IGURE 1$',100,3.5,-.75)                            PL000590
C     CALL MESSAG('     IFD RESULTS -- 10 DEGREE SLOPE$',                PL000600
C    #                100,1.4,6.40)                                     PL000610
      CALL YAXANG(0.0)                                                   PL000620
C     CALL HEIGHT(0.09)                                                  PL000630
      CALL RESET('SWISSM')                                               PL000640
      CALL GRAF(1400.0,100.,2000.0,121,-20.0,1.0)                        PL000650
      CALL ECOMON(20000)                                                 PL000660
      CALL HEIGHT(0.125)                                                 PL000670
      CALL CONMAK(A,M,N,1)                                               PL000680
      CALL CONLIN(0,'SOLID','LABELS',1,10)                               PL000690
      CALL CONANG(90.)                                                   PL000700
      CALL BASPLN(2.50)                                                  PL000710
C     CALL LINEAR                                                        PL000720
      CALL CONTUR(1,'LABELS','DRAW')                                     PL000730
      CALL DOT                                                           PL000740
      CALL GRID(1,1)                                                     PL000750
      CALL ENDPL(0)                                                      PL000760
      CALL DONEPL                                                        PL000770
      STOP                                                               PL000780
      END                                                                PL000790
```

APPENDIX C

RUNNING THE CONTOUR PLOT ON THE NPS COMPUTER

A. INTRODUCTION

This Appendix describes a procedure for running the TL contour plot on the NPS computer. Detailed instructions for running the IFD program can be found in Jaeger(1983).

B. COPYING THE FILE FOR USE

Once the TL values have been generated by the IFD program, all that is needed to produce a TL contour plot is the file PLOTS FORTRAN. This file is shown in Appendix E and can be copied from a computer account maintained by the Underwater Acoustics Curriculum. To link with this account and obtain a copy of the file, the user should proceed as follows:

(1) Log on terminal.

(2) Enter: CP LINK 0160P 191 195 RR .

(3) When prompted for the read password enter: UX .

(4) Enter: ACC 195 C .

(5) Enter: COPY PLOTS FORTRAN C = = A .

At this point the PLOTS FORTRAN file should reside on the user's A disk.

C. RUNNING THE PROGRAM

Before running the program the user must obtain the TL values from the IFD program. These TL values must be sent to

a data disk in order for the PLOTS program to be able to use them. This can be done by placing a WRITE statement in the IFD program that sends the values to a data disk. The modified IFD depicted in Appendix A uses this technique and can be used as a guide.

Once the data disk has been created, the user must assign temporary disk space (TDISK) to give the program sufficient room to generate the IL contours. For more information on how to assign temporary disk space, see NPS Technical Note TN-VM-C1 which is availible in the computer consultant's office.

With these initial steps completed, all that remains is to compile and run the program. The program can be compiled by:

Enter: FORTGI PLOTS .

The program must be run at the TEK618 graphics terminal under DISSPLA. This can be done by:

Enter: DISSPLA .

The user will then be prompted for the compiled Fortran program name and the file definitions for the data disk, before the program will run.

APPENDIX D
SOURCE DEPTH SENSITIVITY ANALYSIS

During the laboratory experiment, two supplemental sets of measurements were taken to obtain an indication of the sensitivity of the pressure amplitude to changes in the source depth. The first set of measurements was obtained by varying the source depth with the receiver fixed at 1.0X (4.8 cm from the beach), and lowered in depth to the bottom. For the second set of measurements, The receiver was fixed at the third dump distance (14.4 cm from the beach), and measurements were taken with the source fixed at 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27, 29, and and 31 cm from the surface.

The results of the first analysis are shown in Figure D.1. In the figure, pressure was normalized by dividing by the maximum pressure and depth was normalized by dividing by the depth of the water column. Although theory predicts only one propagating mode at this distance, the results show modal phase interference.

The results of the second analysis are shown in Figure D.2 through Figure D.6. In the figures, each curve represents a set of measurements taken with the source fixed at a specific depth. For convenience, more than one curve is shown on a given figure. All pressure values were normalized by dividing by the the maximum pressure in the field. The depth values were normalized by dividing by the maximum water depth.

In general, at 3.0X there appears to be modal phase interference which is influenced by source depth. Given the roughness of this analysis, the details of this interference are obscure. However, the modal interference does not appear

to be incorsistent with either the placement of the scurce or with the previous experimental measurements.

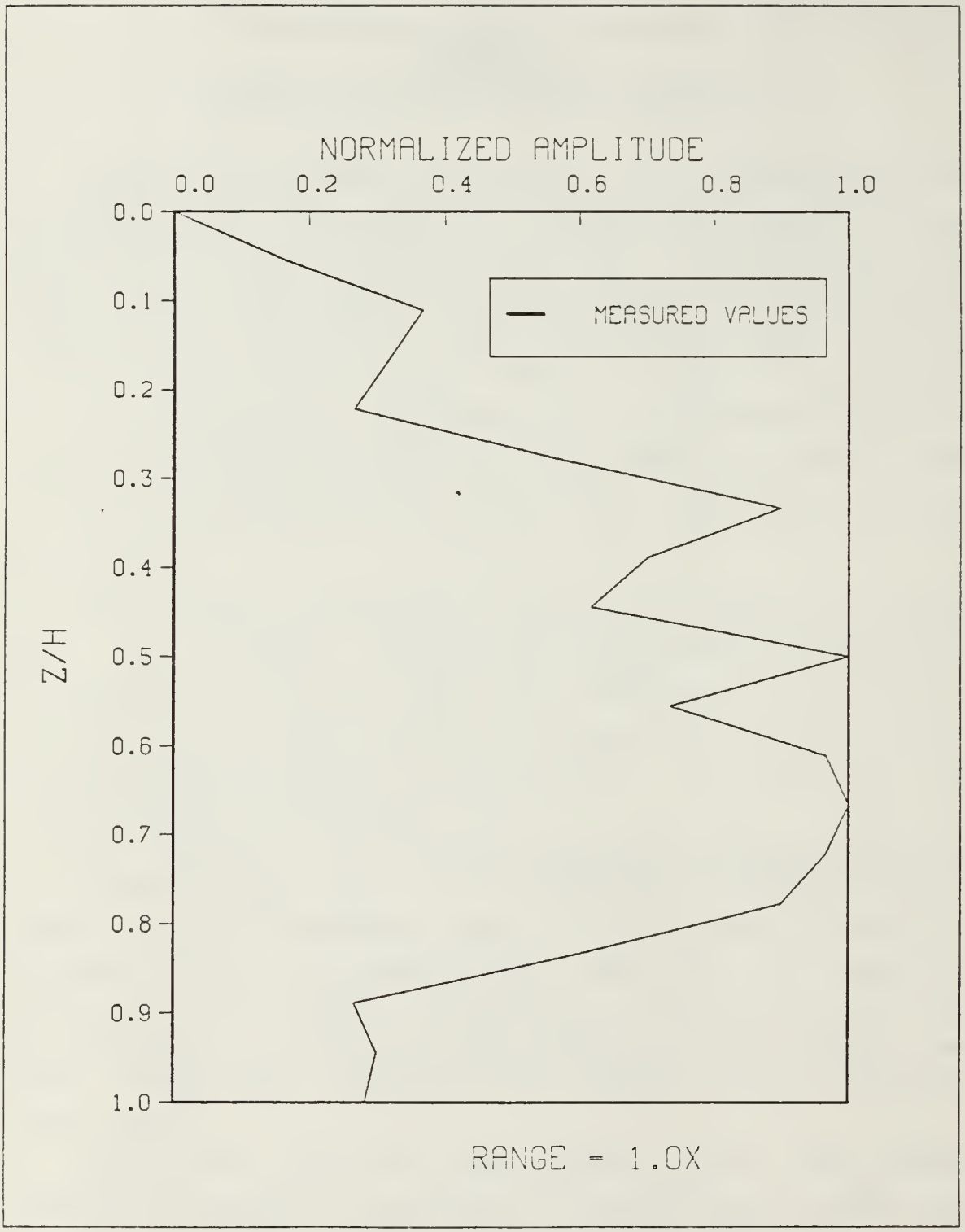

Figure D.1 Source Sensitivity Analysis at 1.0X.

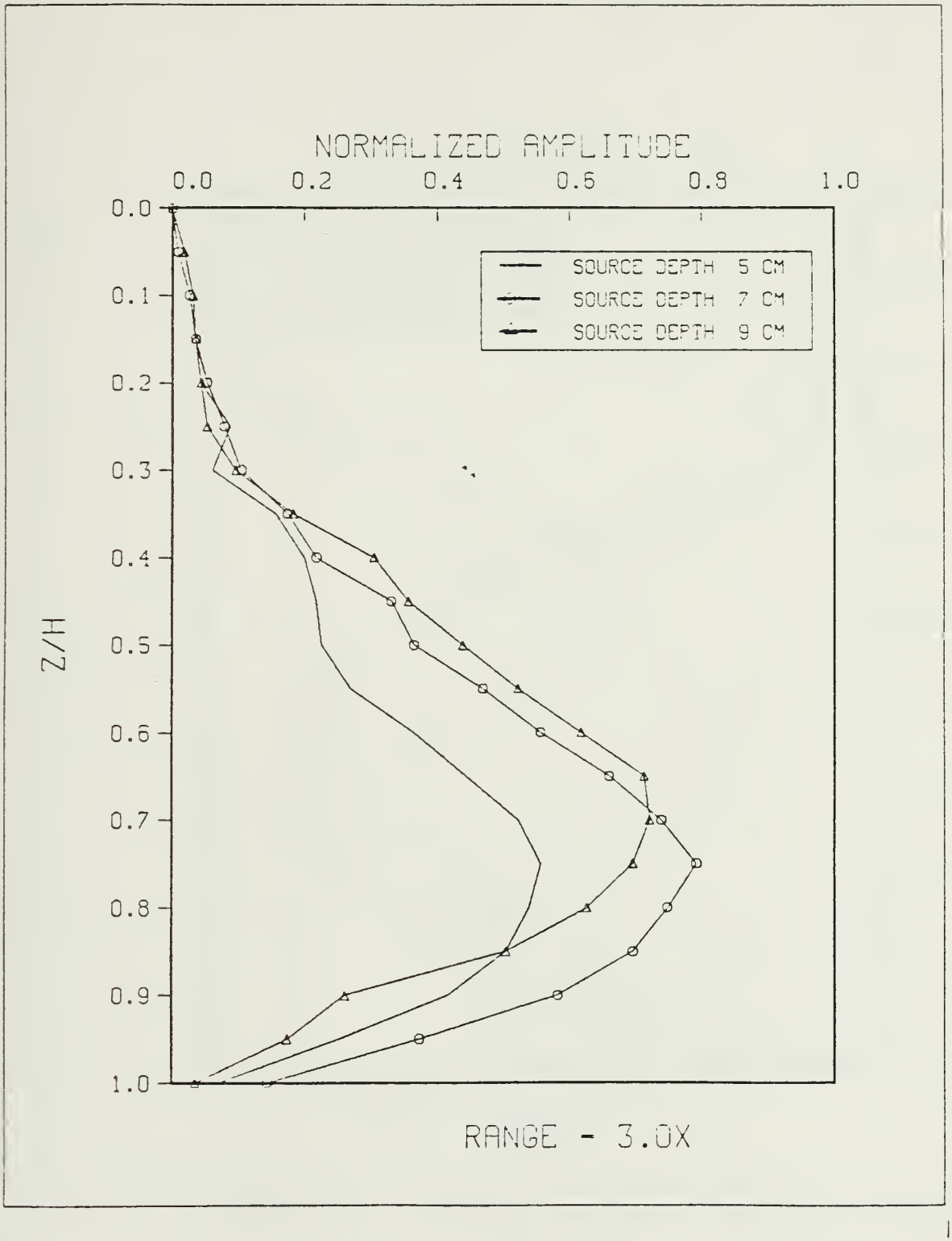

Figure D.2 Measurements with Source Depth of 5, 7, and 9 Cm.

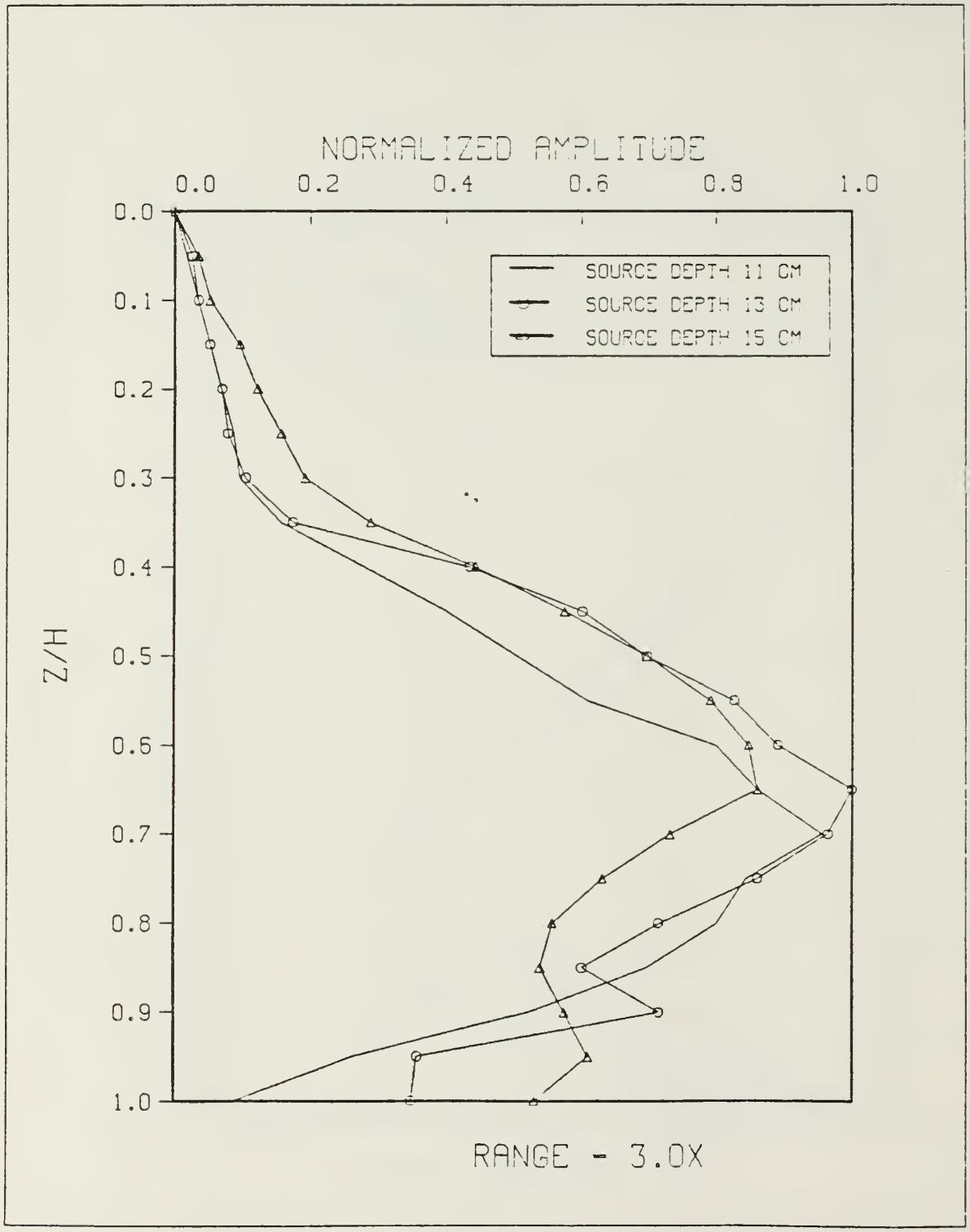

Figure D.3 Measurements with Source Depth of 11, 13, and 15 Cm.

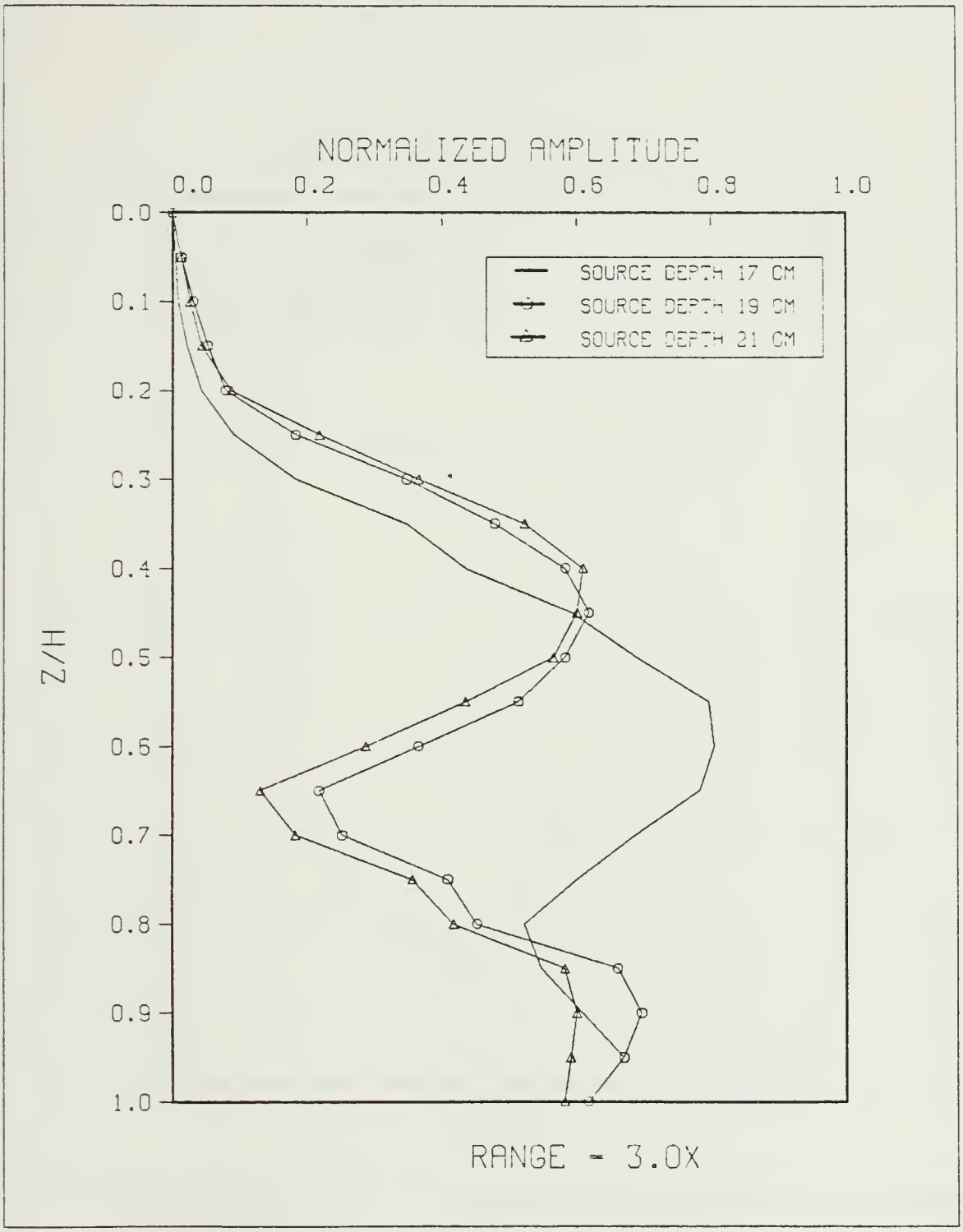

Figure D.4 Measurements with Source Depth of 17, 19, and 21 Cm.

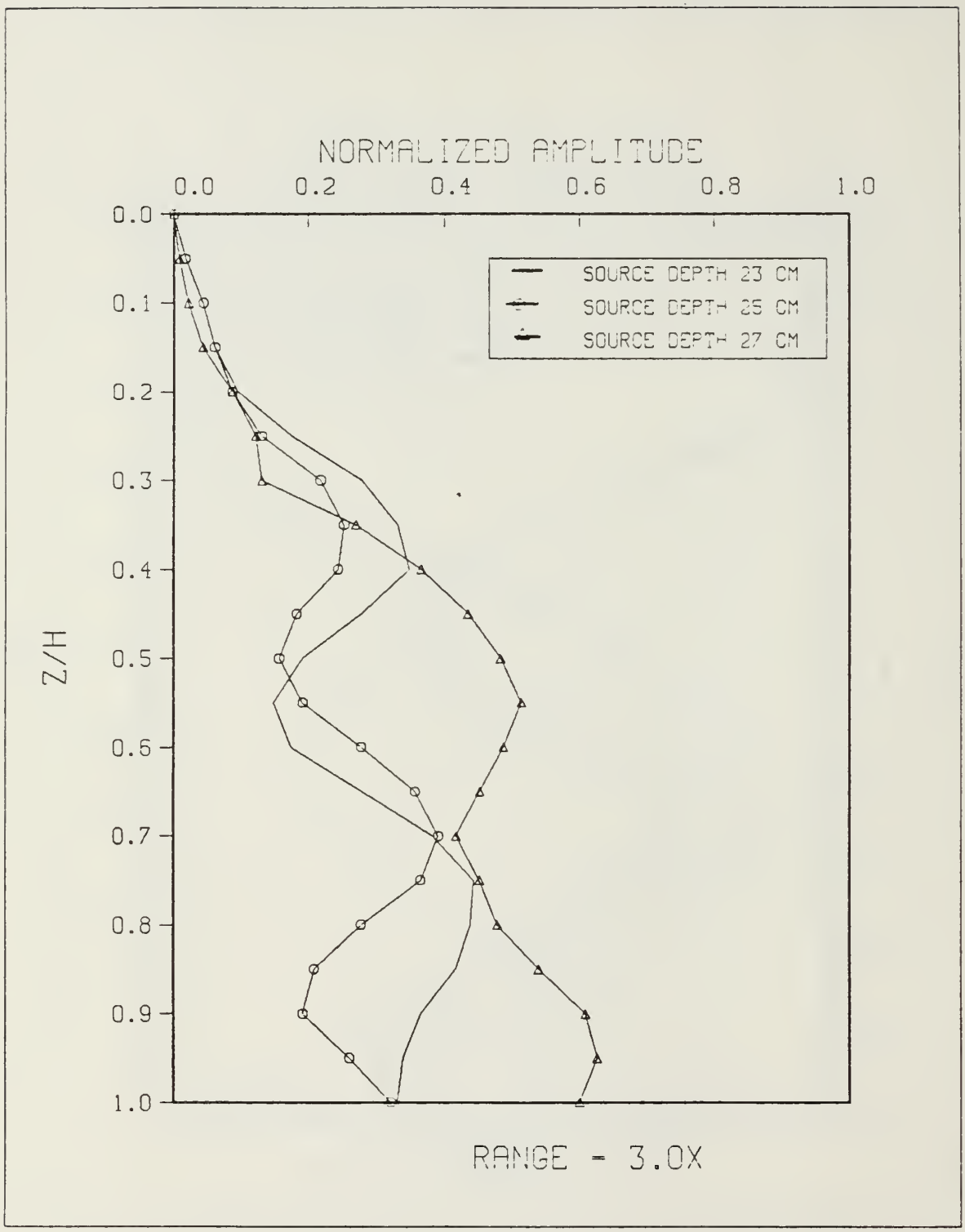

Figure D.5 Measurements with Source Depth of 23, 25, and 27 Cm.

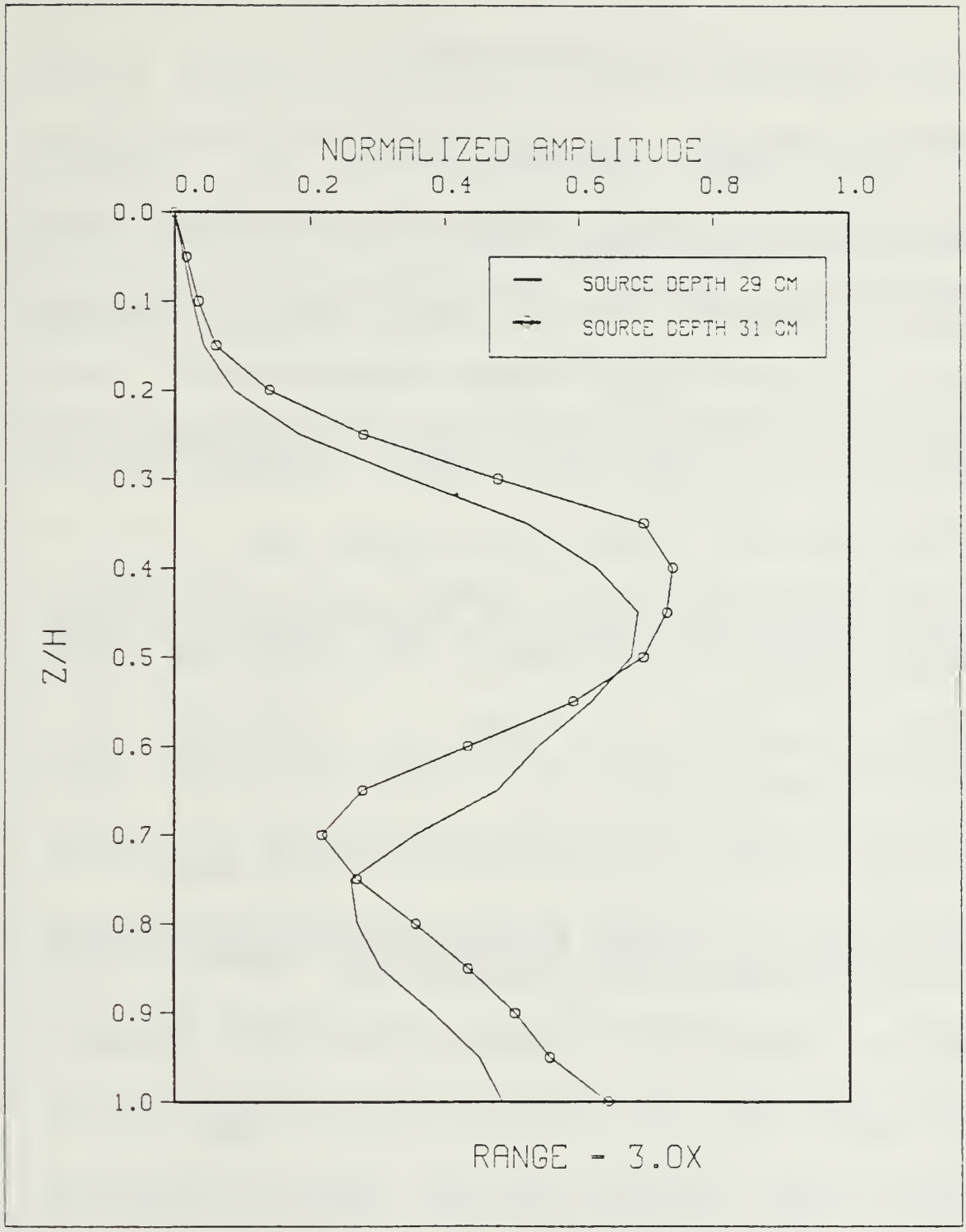

Figure D.6 Measurements with Source Depth of 29 and 31 Cm.

BIBLIOGRAPHY

Anderson, C.L., and Liebermann, R.C., "Sound Velocities In Rocks And Minerals," Physical Acoustics, IV-B, Edited by W.P. Mason, Academic Press, 1968.

Baek, C.K., The Accustic Pressure In A Wedge-Shaped Water Layer Overlying A Fast Fluid Bottom, Master's Thesis, Naval Postgraduate School, March, 1984.

Bradshaw, J.A., Laboratory Study Of Sound Propagation Into A Fast Bottom Medium, Master's Thesis, Naval Postgraduate School, June, 1981.

Brock, H.K., The AESD Parabolic Equation Model, NORDA Technical Note 12, January, 1978.

Coppens, A.E., Humphries, and Sanders, J.V., "Propagation Of Sound Out Of A Fluid Wedge Into An Underlying Fluid Substrate Of Greater Sound Speed", Accepted for For Publication by JASA, May 1984.

Coppens, A.E., and Sanders, J.V., "Propagation Of Sound From A Fluid Wedge Into A Fast Bottom," PLENUM, 1980.

Coppens, A.E., Sanders, J.V., Icannou, G.I., and Kawamura, M., Two Computer Programs For The Evaluation Of The Accustic Pressure Amplitude And Phase At The Bottom Of A Wedge Shaped, Fluid Layer Overlaying A Fast Fluid Half Space, Naval Postgraduate School Technical Report NPS 61-79-002, December, 1978.

Graves, R.P., Nagel, A., Uberall, H., and Zauer, G.I., "Range Dependent Normal Modes In Underwater Sound Propagation: Application To A Wedge Shaped Ocean," JASA, Vol. 58, December 1975.

Hardin, R.H., and Tappert, F.D., "Applications Of The Split Step Fourier Method To The Numerical Solution On Nonlinear And Variable Coefficient Wave Equations," SIAM Review, Vol. 15, 1973.

Jaeger, L.E., A Computer Program For Solving The Parabolic Equation Using An Implicit Finite-Difference Solution Method Incorporating Exact Interface Conditions, Master's Thesis, Naval Postgraduate School, September, 1983.

Jensen, F.B., and Kuperman W.A., Environmental Accustical Modeling At SACLANTCEN, SACLANTCEN Report SR-34, November, 1979.

Jensen, F.B., and Kuperman, W.A., "Sound Propagation In A Wedge-Shaped Ocean With A Penetrable Bottom," JASA, Vol. 67, May, 1980.

Jensen, F.B., and Krol, H., The Use Of The Parabolic Equation Method In Sound Propagation Modeling, SACLANTCEN Memorandum SM-72, August, 1975.

Kawamura, M., and Icannou, I., Pressure On The Interface Between A Converging Fluid Wedge And A Fast Fluid Bottom, Master's Thesis, Naval Postgraduate School, December, 1978.

Kinsler, L.E., Frey, A.R., Coppens, A.B., AND Sanders, J.V., Fundamentals Of Acoustics, Third Edition, John Wiley and Sons, 1982.

Lee, D., and Botseas, G., IFD: An Implicit Finite-Difference Computer Model For Solving The Parabolic Equation, NUSC Technical Report 6659, May, 1982.

Lee, D., Botseas, G., and Papadakis, J.S., "Finite-Difference Solution To The Parabolic Equation," JASA, Vol. 70, September, 1981.

Lee, D., and McDaniel, S.T., "A Finite-Difference Treatment Of Interface Conditions For The Parabolic Equation: The Irregular Interface," JASA, Vol. 73, May, 1983.

Lee, D., and Papadakis, J.S., Numerical Solutions Of Underwater Acoustic Wave Propagation Problems, NUSC Technical Report 5929, February, 1979.

LeSesne, P., Personal Communication, 11 May 1984.

McDaniel, S.T., and Lee, D., "A Finite-Difference Treatment Of Interface Conditions For The Parabolic Equation: The Horizontal Interface," JASA, Vol. 71, April, 1982.

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